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THE COMPOUND STEAM ENGINE, CONSIDERED IN CONNECTION WITH ITS STEAM-GENERATING PLANT.

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II.

II. THE BOILER.

The use of higher steam pressures in marine boilers, which was a part of the change made in introducing the double-cylinder engine, rendered it necessary to abandon the rectangular form of boiler, and to replace it by a boiler with cylindrical shell, this shell containing large flues in which the furnaces were located, and return fire-tubes over these flues. Such a boiler may be regarded as the standard type adopted for marine use at present. The material composing the shell and flues must be made very thick, so that a modern marine boiler is not only very heavy; but the great thickness of the flues prevents the ready transfer of heat, and repairs are frequently necessary. It is very evident, from the costly experiments made by steamship companies with several types of water-tube or sectional boilers, that a reliable and efficient substitute for the cylindrical marine boiler would gladly be adopted, if it could be found. Some examples of the performance of the most prominent types of steam boilers may aid in the solution of this question, and may furnish some hints to those who use boilers in connection with stationary engines.

How much water a good boiler ought to evaporate for each pound of fuel consumed is a question which requires for its answer some knowledge of the theoretical value of this fuel, or its total heat of combustion. Messrs. Favre and Silbermann have determined the total heat of combustion of carbon and hydrogen, which form the combustible elements of coal, and it has been inferred, very naturally, that the results obtained by these experimenters could be used to determine the total heat of combustion of a variety of coal whose analysis was known. So natural, indeed, did this inference appear to be that, so far as can be determined from published records, it was not until 1867 or 1868 that any one thought of testing the truth of the inference by experiment. About this time Messrs. Kestner and Meunier commenced to make experiments on the total heat of combustion of the elementary combustible compounds of the coal, and then of the coal itself. These experimenters made use of apparatus substantially similar to that employed by Messrs. Favre and Silbermann, and obtained results which were nearly the same as those given by the earlier experiments. On testing the total heat of combustion of different varieties of coal, however, Messrs. Kestner and Meunier

TABLE XI.

SUMMARY OF EXPERIMENTS BY MESSRS. KESTNER AND MEUNIER ON HEAT OF COMBUSTION OF VARIOUS COALS.

Number for reference.	Name.	Combustible and volatile constituents.			Heat of combustion per lb. of combustible, by experiment.	
		Carbon.	Hydrogen.	Nitrogen and oxygen.	Thermal units.	Pounds of water evaporated from and at 212°.
1	Saarbrück, Sulzbach	83.05	4.95	12.	15,485	16.02
2	" Von der Heydt	81.56	4.98	13.46	15,232	15 76
3	Creusot, caking (Chaptal shaft)	88.48	4.41	7.11	17,320	17.92
4	" anthracite (St. Pierre shaft).	92.36	3.66	3.98	17,021	17.61
5	" semi-bituminous (St. Paul)..	90.07	4.1	5.13	16,965	17.55
6	" flaming (St. Paul)	90.79	4.24	4.97	16,673	17.25
7	Blanzy, Montceau,	78.58	5.23	16.19	14,985	15.5
8	" anthracite	87.02	4.72	8.26	16,400	16.97
9	Anzin	84.45	4.21	11.32	16,663	17.24
10	Denain	83.94	4.43	11.63	16,290	16.85
11	English, Bwlf	91.08	3.83	5.09	15,804	16.35
12	" Powell Duffryn	92.49	4.04	3.47	16,108	16.66
13	Russian, Grouchefski anthracite	96.66	1.35	1.99	14,866	15.38
14	" Miouski caking	91.45	4.5	4.05	15,651	16.19
15	" Goloubofski flaming	82.67	5.07	12.26	14,438	14.94
16	Lignite, blue, from Rocher	72.98	4.04	22.98	11,669	12.07
17	" flaming, from Manosque	70 57	5.44	23.99	13,253	13.71
18	" lean, from Manosque	66.31	4.85	28.84	12,584	13.02
19	" caking, from Bohemia	76.58	8.27	15.15	14,263	14.76
20	" changing to fossil-wood	66.51	4.72	28.77	11,444	11.84
21	Fossil-wood, changing to lignite	67.60	4.55	27.85	11,360	11 75
22	Russian lignite, from Toula	73.72	6.09	20.19	13,837	14.31

TABLE XII.

COMBUSTIBLE CONSTITUENTS OF AMERICAN COALS, AND POUNDS OF AIR SUPPLIED PER POUND OF COAL, AS DETERMINED BY PROF. JOHNSON.

Number for reference.	Locality.	Designation of Coal.	Combustible constituents, parts in 100.		Lbs. of water evaporated from and at 212° per lb. of combustible, in experimental boiler.	Lbs. of air supplied per lb. of coal.
			Fixed Carbon	Volatile combustible.		
1	Pennsylvania.	Beaver Meadow, Slope No. 3.	97.38	2.62	10.11	20.4
2	" .	Beaver Meadow, Slope No. 5.	97.11	2.89	10.84	28.5
3	" .	Forest Improvement	96.71	3.29	11.02	21.7
4	" .	Peach Mountain	96.77	3.23	11.05	18.4
5	" .	Lehigh	94 41	5.59	9.75	47.9
6	" .	Lackawanna	95.61	4.39	10.93	19 4
7	Virginia	Natural Coke of Virginia	85.33	14.67	10.63	19.7
8	Maryland	Neff's Cumberland	85.47	14.53	10.81	20.1
9	"	Atkinson & Templeman	83.16	16.84	11.87	18.3
10	Virginia	Midlothian, screened	60.77	39.23	10.18	19.9
11	Pennsylvania.	Cannellton	63.23	36.77	7.88	15.9

found that it exceeded, in every instance, the heat as calculated from the combined effects of the combustible elements of the fuel. Their experiments were very extended, and their mode of experimenting and their results have been published in the "Bulletin de la Société Industrielle de Mulhouse," 1868, 1869, 1871; in the "Annales de Chimie," 4th Series, XXX., 5th Series, II, XXI, 6th Series, II; and in the "Comptes Rendus de l'Académie," 2d Series, 1869. Table XI. contains a summary of the most important results of these experiments, and shows conclusively that the ordinary method of estimating the heat of combustion of a given fuel from its elementary analysis is entirely erroneous. There are no American coals in this table, but as the best anthracite coal of the United States contains more fixed carbon than any specimen of Table XI. (See Table XII.) It is reasonable to suppose that it is at least equal in heating effect to the best European coal tested by Messrs. Kestner and Meunier.

The results given in the preceding table are now generally used by European engineers in their calculations. Dr. Percy, in referring to the experiments of Messrs. Kestner and Meunier, states that more extended data will be necessary for the explanation of the results. M. L. Gruner, however, in a very interesting article on "The Classification and Heating Power of Coals" (a translation of which is published in the *Engineering and Mining Journal*, vol. XVIII.), shows clearly that it is the generally accepted formula which is anomalous, rather than the results. He remarks as follows:

"Dulong proposed the formula:

$$P = 14544\,C + 62032\,(H - \frac{O}{8})$$; where P = heating power in thermal units, C = weight of carbon in pounds, $H - \frac{O}{8}$ = weight of *free* hydrogen, *i. e.*, the total hydrogen less that already burnt to *water* by the oxygen that the coal contains. Doubtless Dulong considered this formula as giving only a kind of *industrial* value, for he knew well enough that we cannot, in a calorific sense, assimilate a ternary chemical compound to a simple mixture of C and H; and that the H is not simply combined with the O in coal. But at that time, at least, it was thought that C and H, considered as simple bodies, possessed always the same calorific power. The influence of molecular construction on the calorific power of bodies was ignored; it was not known that the heat of combustion of a body, simple or compound, is, in general, greater in proportion as its molecular condensation is less advanced.

"It is now established by the labors of Favre, Silbermann, Regnault, Berthelot and others, that the heat of combustion, like the specific heat, varies with the density.

	Heat units.
"We know that if carbon from wood charcoal develops	14544,
The charcoal of gas retorts, which is more dense, gives only	14485.
Natural graphite	14035.
The diamond only	13986.
We know also that the heating power of crystallized sulphur is	4072,
While that of the denser amorphous S, run in a melted state into water, is only	3991.

"It follows from this that to apply Dulong's formula to coals, we should substitute for the calorific power of hydrogen in a gaseous state that of hydrogen in a solid state, and, instead of 14544, which represents the heat of combustion of carbon having, according to M. Violette, a density greater than 2, we should put the greater number corresponding to the less condensed state of the carbon in coals.

* * * * *

"The actual heating power of all fuels, except the bituminous lignite of Bohemia (which, from the large amount of hydrogen it contains, resembles the petroleums) is not only greater than the heating power calculated by Dulong's formula, but, also, for the anthracites and bituminous coals, it is greater than the sum of the heat units due to the entire amount of carbon and hydrogen contained in them, taking them as isolated, and after making deduction for the oxygen.

"Thus, coal from the Chaptal mine gave	17320 heat units against C+H=15606
Coal from the Ronchamp mine gave	16399 heat units against C+H=15822
Coal from the Denain mine gave	16290 heat units against C+H=14958
Coal from the Louisenthal mine gave	14787 heat units against C+H=14083

"M. Scheurer Kestner, noticing this apparent anomaly, concluded that the combination of carbon and hydrogen in coals was attended with absorption of heat, as is the case with explosive compounds. The anomaly is, however, only apparent. Coal has none of the properties of explosive substances, and if the actual heating power is higher than that obtained from calculation, it is, as we have already remarked, because we take the figures 14544 heat units for carbon, while, in reality, we should take a number nearer to 20186, which is the theoretic heating power of carbon in the form of gas.

"The number 20186 heat units is obtained as follows: We know that carbon develops 4451 heat units when it is transformed into oxyd of carbon, and this gas, in its turn, gives (14544—4451) =10093 heat units in combining with a new equivalent of oxygen; that is, equal quantities of oxygen apparently develop very unequal quantities of heat; I say *apparently*, for in the first case the solid carbon passes to the gaseous condition, while in the combustion of carbonic oxyd it is carbon in the condition of gas that burns. Now, if we admit with Rankine that Welther's law obtains so long as the chemical reactions are neither accompanied nor followed by a change of condition, we see that the excess of (10093 —4451)=5642 heat units should correspond exactly with the heat absorbed by the gasification of carbon, and consequently gaseous carbon would develop (14544+5642)=20186 thermal units, if it gave carbonic acid directly.

"In any case it is evident that considering this number 20186 heat units merely as the result of a purely theoretical speculation, the but *slightly condensed* carbon of bituminous coal should produce more heat than pure carbon from wood charcoal. On the other hand, for *solid* hydrogen we should take a number smaller than 62032 heat units, which corresponds to gaseous hydrogen producing water, which is also taken in the gaseous state.

"We can readily satisfy ourselves that we would obtain values nearer the truth by assuming, for example, 16200 heat units as the heat of combustion of carbon in coal, and 54000 heat units as that of solid hydrogen; we would thus find, after deducting for the oxygen:

"For coal from Anzin...	15957	instead of	16663
For coal from Denain..	15989	"	16290
For short-flaming fat coal from the Chaptal mine (Creuzot).....	16715	"	17320
For coal from Ronchamp.	16893	"	16399
For dry coal from Montceau.....	15554	"	14985
For dry coal from Louisenthal.....	14980	"	14787

"The agreement is not, however, satisfactory; we note that the calculation gives too low a value for coals rich in fixed carbon, and, on the other hand, too high a value for those which leave but little coke. In brief, it is evident that the manner of combination of the elements in coals is too variable to make it possible to determine their true heating power from simple elementary analysis. We must, therefore, determine by direct experiment the heating power of each kind of coal, or else we must be satisfied with the mean results which we obtain by combining the Mulhouse experiments—a summary of which is given in the above table—with the numerous industrial tests made by Dr. Brix, in Berlin, and by the French and English navies."

The useful heating effect obtained from coal consumed in the furnace of a boiler is, of course, considerably less than the total heating effect, on account of such inevitable losses as the amount of heat carried off in the products of combustion, the unconsumed fuel that drops through the air spaces of the grates, the loss due to imperfect combustion, and the heat radiated from the external surfaces of the boiler or its setting. The useful heating effect depends also upon the proportions and design of the boiler, and upon the amount of air admitted to the furnace. In regard to the amount of air required for combustion it is commonly assumed, from the experiments of Prof. Johnson ("Report to the Navy Department of the United States, on American coals," Washington, 1844), that with natural draft, the air supplied should be twice the amount theoretically required, or about 25 lbs. of air per lb. of coal burned. The experiments of Prof. Johnson hardly bear out this idea, as will appear from an inspection of Table XII., which has been taken from the report cited above. Messrs. Kestner and Meunier, after determining the total heating effect of different varieties of European

Table XIII.

Heat of Combustion of Foreign Coals, and Pounds of Air Supplied per Pound of Coal, as Determined by Messrs. Kestner and Meunier.

Number for reference.	Designation of Fuel.	Heat of combustion, in thermal units, per lb. of combustible, by experiment.	Useful effect, per pound of combustible, in experimental boiler.		Pounds of air supplied per pound of coal.
			Thermal units.	Pounds of water evaporated from and at 212°.	
1	Ronchamp, No. 1	16,346	10,057	10.4	12.6
2	" No. 2	16,411	10,438	10.8	12.8
3	Friedrichsthal	15,223	8,928	9.24	12.6
4	Duttweiler	15,703	9,484	9.81	13.4
5	Luisenthal	14,787	8,348	8.64	11.5
6	Altenwald	15,539	9,421	9.75	12.8
7	Heinitz	15,277	8,941	9.25	11.8
8	Sulzbach	15,212	8,847	9.15	13.5
9	Von der Heydt	15,232	8,789	9.09	12.6
10	Blanzy, Montceau	14,985	8,446	8.74	10.6
11	" anthracite	16,380	9,920	10.26	12.5
12	Creusot	16,942	10,472	10.83	20.5
13	⅔ Creusot, ⅓ Ronchamp No. 1.	16,758	11,268	11.66	17.1
14	⅔ Creusot, ⅓ Ronchamp No. 2.	16,758	11,131	11.52	16.1
15	Wood charcoal	14,544	8,698	9.	23.4

coal, experimented with several of the varieties in the furnace of a steam boiler. They also tried the effect of admitting different amounts of air, and found that the best results with natural draft were obtained when the air supply was about $1\frac{1}{3}$ times the amount theoretically required. A summary of the results obtained by Messrs. Kestner and Meunier is given in Table XIII.

It may be useful to illustrate by an example. the effect of employing an erroneous assumption instead of an experimental result in a discussion of boiler performance. The experiment selected for discussion is No. 9, Table XXV., and the actual performance will be compared with the maximum that is theoretically possible by experiment and by assumption.

The reader will find the results of a number of boiler experiments in the following tables, experiments generally regarded as being among the most reliable that have ever been made, all of which must be repudiated by those who believe that the maximum heating effect attainable from the combustible in the best varieties of American anthracite is 14,544

	By experiment, Table XI, Example 3.	By assumption, Table XIII, Example 15.
Total heating effect of a lb. of combustible, thermal units	17,320	14,544
Per cent. of combustible in a lb. of coal, Table XXV, Experiment 9	82.7	82.7
Thermal units per lb. of coal, maximum heating effect	14,324	12,028
Temperature of fire-room	68°	68°
Temperature of escaping products of combustion, at least	600°	600°
Lbs. of air supplied per lb. of coal	19	25
Specific heat of products of combustion	0.237	0.238
Thermal units carried off in products of combustion	2,406	3,165
Maximum possible evaporation, thermal units	11,918	8,863
Evaporation by experiment, thermal units	10,636	10,636
Temperature of furnace	3832°	2440°

thermal units per lb., and that the average amount of air supplied to furnaces consuming American anthracite is from 25 to 30 lbs. per lb. of coal.

Supposing the furnace of a boiler to be so arranged that the proper amount of air for economical evaporation is admitted, it will be found that the evaporation actually obtained depends upon the proportions of the boiler, and the character and disposition of the heating surfaces. The rate of transmission of heat through a metallic plate covered with water on one side, and exposed to the action of flame or heated gases on the other, has been found by experiment to depend upon the difference of temperature on the two sides of the plate, or rather upon the square of this difference, from which fact it can reasonably be inferred that the heating surfaces nearest to the fire are the most efficient, so that, other things being equal, the boiler which has the largest proportion of furnace heating-surface will be the most efficient and the most economical. This inference is fully sustained by experiment, as will be shown. To determine the effect of different arrangements of heating-surface and other details, it is useful to examine the results of experiments in which the same kind of coal was used and the same method of experimenting, with boilers of various design. Such a series of experiments is contained in the "Reports and Awards, group XX," of the United States International Exhibition, 1876. Philadelphia, 1878. In this report will be found full details of experiments made with fourteen different boilers, eight of which were of the sectional or water-tube variety. These experiments have sometimes been incorrectly reported in the trade circulars of boiler manufacturers, and have been accompanied by discussions of results that were generally in the interest of particular boilers. The report, however, is of great value to any one who examines it impartially, and the writer hopes that the following tables will prove useful both to boiler manufacturers and steam users. Nearly all the boilers tested at the Centennial Exhibition were of well-known forms, and designating letters have been applied to them, as follows:

BOILERS TESTED AT CENTENNIAL EXHIBITION, 1876.

A.—*Wiegand*, water-tube boiler.

B.—*Harrison*, sectional boiler, cast-iron.

C.—*Firmenich*, water-tube boiler.

D.—*Rogers & Black*, vertical cylinder, suspended over grate, the cylinder having external water-tubes arranged vertically around it.

E.—*Andrews*, double-return tubular, with sheet-iron smoke-connections.

F.—*Root*, water-tube boiler.

G.—*Kelly*, water-tube boiler.

H.—*Exeter*, sectional boiler, cast-iron.

I.—*Lowe*, cylindrical tubular boiler, with combustion chamber in front-connection.

J.—*Babcock & Wilcox*, water-tube boiler.

K.—*Smith*, cylindrical tubular boiler, with generator attachment, consisting of water bridge-wall, and pipes at sides of furnace and under shell of boiler beyond bridge-wall.

L.—*Galloway*, flue boiler, furnaces in two flues, which unite beyond the grates in an elliptical flue which is crossed by conical water-tubes.

L'.—*Galloway*, same as preceding, tried with bituminous coal.

M.—*Anderson*, water-tube boiler.

N.—*Pierce*, tubular cylinder, revolving on trunnions over the grate.

An attempt is made, in the following discussion, to determine the relative commercial value of each boiler, and to find the reasons that influence this value.

Table XIV. shows the relative standing of the boilers in respect to their economical performance, and in Table XV. the relative consumption of fuel per unit of capacity or horse-power has been determined, on the assumption that a boiler horse-power is represented by the evaporation of 30 lbs. of water per hour, from and at 212°. The same unit of horse-power is used in all the boiler experiments that follow. The results given in Tables XIV. and XV. show that the effect of increasing the rate of combustion generally decreases the economical performance to a marked extent, so that a boiler which is quite economical when tested for economy may have its position materially changed when it is operated at full capacity. The

Table XIV.

Centennial Boiler Tests.—Pounds of Water Evaporated from and at 212°, per Pound of Combustible.

Relative Number.	Capacity Tests.		Economy Tests.		Average of Capacity and Economy Tests.	
	Boiler.	Evaporation.	Boiler.	Evaporation.	Boiler.	Evaporation.
1	K	11.925	L′	12.125	K	11.916
2	L′	11.609	F	12.094	L′	11.867
3	L	11.216	C	11.988	I	11 543
4	I	11 163	I	11.923	C	11.526
5	C	11.064	K	11.906	L	11.400
6	F	10.441	J	11.822	F	11.268
7	J	10.330	L	11.583	J	11.076
8	H	9.974	E	11.039	B	10.410
9	B	9.889	B	10.930	E	10 392
10	N	9.865	A	10.834	M	10 093
11	E	9.745	M	10.618	H	10.008
12	M	9.568	G	10.312	A	9.990
13	D	9.429	H	10.041	N	9.943
14	A	9.145	N	10.021	D	9.521
15	G	8.397	D	9.613	G	9.355

Table XV.

Centennial Boiler Tests.—Pounds of Combustible per Hour, per Horse-Power Developed.

Relative Number.	Capacity Tests.		Economy Tests.		Average of Capacity and Economy Tests.	
	Boiler.	Combustible	Boiler.	Combustible	Boiler.	Combustible
1	K	2.51	L′	2.47	K	2.52
2	L′	2.58	F	2.48	L′	2.53
3	I	2.67	C	2.50	I	2.60
4	L	2.67	I	2.52	C	2.61
5	C	2.71	K	2.52	L	2.63
6	F	2.87	J	2 54	F	2 68
7	J	2.90	L	2.59	J	2.72
8	H	3.01	E	2.72	B	2.89
9	N	3.04	B	2.74	E	2.90
10	B	3.04	A	2.77	M	2.98
11	E	3.08	M	2.83	H	3.01
12	M	3.13	G	2.91	N	3.02
13	D	3.18	N	2.99	A	3.03
14	A	3.28	H	3.00	D	3 15
15	G	3.57	D	3.12	G	3.24

economical performance of a boiler, generally speaking, depends upon the rate of combustion per unit of heating-surface, the economy ordinarily decreasing as the rate of combustion increases. It is important, therefore, in considering tests of boilers where the rates of combustion per unit of heating-surface vary, to reduce the results to some common standard before comparing them. This can be done approximately in a manner which will be explained. Prof. Rankine has deduced, from experiment, some formulas for determining the efficiency of a boiler at different rates of combustion. The results obtained from these formulas agree well with the actual performance of boilers of good design, are larger

TABLE XVI.

EFFICIENCY OF BOILERS, AT DIFFERENT RATES OF COMBUSTION,—CALCULATED FROM PROF. RANKINE'S FORMULAS.

Pounds of combustible per hour, per square foot of heating surface.	Evaporative efficiency.			
	Natural draft.		Forced draft.	
	Ordinary setting.	With fuel economiser.	Ordinary setting.	With fuel economiser.
5.	0.282	0.300	0.399	0.412
4.	0.330	0.350	0.456	0.468
3.	0.397	0.420	0 528	0.542
2.	0.503	0.525	0.632	0.644
1.	0.678	0.700	0.780	0.792
0.9	0.705	0.724	0.805	0.811
0.8	0.729	0.750	0.824	0.831
0.7	0.761	0.778	0.844	0.851
0.6	0.790	0.808	0.865	0.873
0.5	0.827	0.840	0.888	0.896
0.4	0.861	0.875	0.911	0.919
0.3	0.906	0.913	0.941	0.945
0.2	0.946	0.955	0.969	0.971
0.1	1.000	1.000	1.000	1.009

TABLE XVII.

CENTENNIAL BOILER TESTS.—RATIO OF ACTUAL AND THEORETICAL EFFICIENCY.

Relative Number.	Capacity Tests.		Economy Tests.		Average of Capacity and Economy Tests.	
	Boiler.	Ratio.	Boiler.	Ratio.	Boiler.	Ratio.
1	L'	1.013	L'	0.992	L'	1.003
2	K	0.982	L	0.976	L	0.975
3	L	0.974	F	0.953	K	0.964
4	N	0.953	K	0.946	N	0.928
5	I	0.914	J	0.941	I	0.915
6	D	0.889	C	0.918	J	0.908
7	J	0.875	I	0.916	F	0.906
8	C	0.870	A	0.910	C	0.894
9	B	0.858	N	0.902	B	0.874
10	F	0.858	G	0.897	E	0.865
11	E	0.841	B	0.890	D	0.860
12	M	0.832	E	0.889	A	0.858
13	A	0.806	M	0.864	G	0.849
14	G	0.801	D	0.830	M	0.848
15	H	0.795	H	0.765	H	0.780

than the actual results obtained from boilers whose design or proportions are faulty, and are too small for the most economical and efficient boilers, as will appear from the applications that follow. Prof. Rankine has tested his formulas by comparison with a number of experimental results, in his "Manual of the Steam-Engine and other Prime Movers," and the writer has applied these formulas to numerous boiler experiments, with very satisfactory results. Table XVI. is computed from the formulas referred to. In order to compare the results given in this table with those obtained experimentally, it is necessary to assume a figure for the

TABLE XVIII.

CENTENNIAL BOILER TESTS.—(EVAPORATION PER POUND OF COMBUSTIBLE) +(RECIPROCAL OF COMBUSTIBLE PER HORSE-POWER)+(RATIO OF EFFICIENCY).

Relative Number.	Capacity Tests.		Economy Tests.		Average of Capacity and Economy Tests.	
	Boiler.	Sum.	Boiler.	Sum.	Boiler.	Sum.
1	K	13.305	L′	13.523	K	13.277
2	L′	13.010	F	13.450	L′	13.265
3	L	12.565	C	13.306	I	12.843
4	I	12.452	K	13.249	C	12.803
5	C	12.303	I	13.236	L	12.755
6	F	11.647	J	13.157	F	12.547
7	J	11.550	L	12.945	J	11.352
8	N	11.147	E	12.296	B	11.630
9	H	11.101	B	12.185	E	11.602
10	B	11.076	M	11.835	M	11.277
11	E	10.911	G	11.553	N	11.202
12	M	10.719	N	11.257	A	11.178
13	D	10.632	H	11.139	H	11.120
14	A	10.256	A	11.105	D	10.698
15	G	9.478	D	10.764	G	10.513

evaporation corresponding to an efficiency of unity, and in order to conform to the principles on which the table depends, the writer has assumed that the evaporation corresponding to this efficiency is equal to 13.5 lbs. of water from and at 212° per lb. of combustible. This figure, like the several efficiencies in the table, will be found to agree well with a good average performance, to be too large for an inferior performance, and smaller than the best actual results. Applying these figures to the experiments under consideration, results are obtained as shown in Table XVII., which table probably represents the true economical values of the different boilers under the different conditions of trial.

By adding the several figures of Table XIV. to the corresponding figures of Table XVII., and to the reciprocals of the corresponding figures in Table XV., the results shown in Table XVIII. are obtained; and these figures seem to represent the relative commercial value of each boiler to the steam user, with the exception of the comparatively unimportant question of first cost, and other questions, by no means unimportant, of relative safety and durability. The last point is scarcely suitable for consideration in the present discussion, but it may be well to remark that any boiler of good design and material, substantially constructed, is quite as safe, under intelligent management (judging from experience and from the premiums demanded by boiler insurance companies), as the best forms of sectional, or, as they are sometimes called, safety boilers; so that a safety boiler managed by an attendant who can be hired cheaply because he is incompetent, will frequently cause a loss to the steam user that would more than pay for the services of a reliable attendant for a more economical boiler which would be quite as safe as the other in all things except the name.

As this view of the matter is not accepted by all engineers, it may be well to cite the opinions of a very high authority on the subject of boiler explosions. The following extract is from a letter addressed to Mr. Charles T. Porter by Mr. L. E. Fletcher, Chief Engineer of the Manchester Steam User's Association. This letter is published in the "Reports and Awards, Group XX." of the United States International Exhibition, Philadelphia, 1878.

"No. 1. *Term of Existence.* — The Association was established in the year 1854, and has been in active work ever since, increasing in the number of boilers and the area of its operations.

"No. 2. *Average and Present Number of Boilers in charge.*—The number of boilers now under inspection is, as

nearly as may be, 3,000. The average for the last five years has been 2,500.

No. 3. *Character of the Boilers, and if of Different Types, the Number of Each.*—By far the greater number of boilers enrolled with the Association are horizontal and internally fired. Speaking approximately, the relative number of the various types is as follows:

"50 per cent. are what are termed 'Lancashire' boilers—that is to say, having two internal tubes running through them from end to end in which the fires are placed.

"15 per cent. are of the 'Cornish' type—that is to say, having one furnace tube running through it from end to end, in which the fire is placed.

"15 per cent. are externally fired, such as plain, cylindrical, egg-ended, colliery boilers; French or 'Elephant' and 'Butterly' boilers.

"8 per cent. are variations of the 'Lancashire' and 'Cornish' boiler, with a number of small flue tubes, some termed 'Multiflued' and others 'Multitubular,' etc.

"6 per cent. are of the 'Galloway' type.

"6 per cent. are of the miscellaneous types, such as boilers at iron-works, heated by flames passing off from puddling and iron furnaces, water-pipe boilers, locomotive and marine boilers, and vertical internally hand-fired boilers, etc.

"These proportions vary somewhat year by year as boilers are changed.

"No. 4. *Pressure carried between what Limits.*—All the 'Lancashire' boilers made for the members under the inspection of the Association, the ruling diameter of which is 7 feet in the shell, and 2 feet 9 inches in the furnace tubes, are fit for a working pressure, as a minimum of 75 pounds on the square inch. Many are fit for a working pressure of 85 pounds, others 90 pounds and 100 pounds. No new boilers are made to the Association's standard for a lower pressure than 75 pounds on the square inch. Many smaller boilers are carrying 120 pounds.

"No. 5. *Character of the examinations made, and their frequency.*—A complete examination of each boiler is made both inside and outside, when at rest and properly prepared, at least once a year, and more often if necessary—that is to say, if the boiler does not appear thoroughly sound or repairs have to be examined. Hydraulic tests are also had recourse to when necessary. In addition to the annual thorough examination, two external examinations of each boiler are made per annum with the boilers at work and steam up. This number is a minimum.

* * * * *

"No. 7. *Instructions given to Owners and Firemen.*—We have no written code, but are thinking of preparing a list of instructions to firemen. All we ask from the owners is to get a good boiler and a careful man. We impose no arbitrary conditions. Information to the owners is always accessible at these offices.

"No. 8. *The Guarantee afforded to Members.*—The Association guarantees the members freedom from explosion year after year. As a pledge of good faith, the reports are endorsed with a pecuniary guarantee of £300; but the Association has no explosions. The only exception to this was the rending of a furnace through over-heating, in consequence of misuse by the owner, who charged the boiler heavily with caustic soda and arsenic, bringing down the incrustation, but yet neglecting to blow out. We warn our members against using compositions and neglecting to blow out. Year after year we are able to report, '*No explosion from any boiler guaranteed by the Association.*'

"No. 9. *The cost to Members of the Inspection and Guarantee.*—The charge for inspection is one guinea and a half per annum each boiler, within a radius of 40 miles of Manchester; beyond that distance, according to arrangement. There is no charge for guarantee. The Association's guarantee is neither to be bought nor sold. If the Association considers a boiler unsafe, nothing will induce it to say it is safe. If a boiler is safe, there is no need to charge for saying so. The expense is incurred in inspection, and the Association has no explosions to make compensation for.

"No. 10. *The Result of the Work of the Association in Immunity from Accidents.*—It is presumed by the word '*accidents*' is meant '*explosions.*' We do not approve of the word '*accidents*' as applied to explosions. Explosions in the great majority of cases are not accidental: they arise from known

causes. Inspection is able to prevent their occurrence, and is found in the experience of the Association to be quite adequate. *See here reply to question No.* 8.

"11. *Upon what do you rely for Safety?*—Upon competent periodical inspection. *See reply to questions* 8 and 10.

With regard to the relative first costs of the boilers tested at the Centennial Exhibition, they can only be inferred from the relative amounts of heating-surface in respect to capacity. If all the boilers were alike in design and made of the same materials, differing only in their proportions, a comparison of this kind would give a close approximation to the relative costs. In the actual case, where one boiler is composed principally of cast-iron, another of wrought-iron, and a third of steel, the comparison, as made in Table XIX., will merely afford an approximate idea of the selling prices.

In the use of steam boilers the demands for steam frequently vary to a considerable extent, so that the boilers are run at times with slow rates of combustion, and at other times are forced to their utmost capacity. Under such circumstances the most economical boiler for the steam user is one that has its evaporative capacity changed the least by a change in the rate of combustion, or, in other words, the boiler which shows the best ratio of evaporation at high and low rates of combustion. The final comparative table of the Centennial boiler tests, Table XX., shows this ratio, as also the theoretical ratio, calculated by Table XVI., together with the actual rates of combustion, and some of the most important proportions of the boilers.

It would, of course, be possible to extend these comparative tables much farther, but it is thought that the most important points determined by the tests have been presented. The tables are so fully detailed that a number of interesting conclusions can be drawn from them. It may be interesting to state briefly sev eral of the most useful. It is to be noticed that the sectional or water-tube boilers represented in these tests were generally less economical than the others, except at slow rates of combustion. Considering only the tests with anthracite coal, it appears that boiler F, the most economical of the sectional boilers in this collection, which was the most economical of all the boilers at a slow rate of combustion, occupies the 6th place under a high rate of combustion, and the same average place. The great loss of economy that occurs in the case of most sectional boilers, when their rate of combustion is fixed at the limits that obtain in ordinary practice, has long been recognized by experienced engineers, and although at first thought it seem unreasonable that boilers whose heating-surface is composed of thin tubes should be less economical than shell boilers composed of thick metal, there is a very good reason for this difference, and an attempt will be made to point it out. Referring to Table XX., it will be seen that the difference in actual evaporation at high and low rates of combustion for the first seven boilers in the table is either practically the same as, or considerably less than, the theoretical difference; and a reference to the designs of these seven boilers shows that each of them has a large amount of furnace heating-surface, all the heating-surface, in fact, of boilers D and N being in the furnace Now, it has already been stated that the transmission of heat through the heating-surface varies as a function of the square of the difference in temperature of the two sides of this surface; and some experiments will be presented, before concluding this paper, to show that in a boiler with good furnace heating-surface, this surface evaporates the greater part of all the water that is made into steam by the boiler. It is probably true that with any design of boiler the evaporative results can be made to equal the best that have been recorded, if the heating-surface is sufficiently extended. But heating-surface costs money, and requires considerable space, so that, if the same results can be obtained with a less amount of heating-surface, properly distributed, the latter design is to be preferred. It seems to be the neglect of the principles here stated which causes most water-tube boilers to give such inferior results at high rates of combustion.

The experiments detailed in Tables XXI., XXII. and XXIII., while of considerable interest, are not as useful for purposes of comparison as those that have just been considered; being made generally, in different localities, with different kinds of coal, and under different

TABLE XIX.

CENTENNIAL BOILER TESTS.—SQUARE FEET OF HEATING-SURFACE PER HORSE-POWER DEVELOPED.

Relative Number.	Capacity Tests.		Economy Tests.		Average of Capacity and Economy Tests.	
	Boiler.	Square Feet.	Boiler.	Square Feet.	Boiler.	Square Feet.
1	N	4.48	N	5.87	N	5.18
2	D	5.17	G	6.83	G	6.18
3	G	5.53	L	7.18	L	6 36
4	L	5.54	D	7.61	D	6.39
5	L′	5.93	A	7.90	L′	7.05
6	A	7.15	L′	8.16	A	7.53
7	B	7.25	B	9.50	B	8.38
8	M	7.30	M	9.89	M	8.60
9	E	7.50	E	10.36	E	8.93
10	J	7.81	J	10.75	J	9.28
11	K	8.03	K	10.78	K	9.41
12	I	9.24	F	11.60	F	10.48
13	F	9.35	I	13.59	I	11.42
14	H	12.60	C	15.53	C	14.33
15	C	13.12	H	18.85	H	15.73

TABLE XX.

CENTENNIAL BOILER TESTS.—DIFFERENCE OF EVAPORATIVE EFFICIENCY, CAPACITY AND ECONOMY TESTS.

Relative Number.	Boiler	Per cent of difference in evaporation, capacity and economy tests.		Pounds of combustible per square foot of heating surface per hour.		Temperature of flue.		Ratio of	
		Actual.	Theoretical.	Capacity tests.	Economy tests.	Capacity tests.	Economy tests.	Heating to grate-surface.	Draft area to grate-surface.
1	K	0.2	3.6	0.313	0.234	435°.06	411°.48	46.16	0.130
2	H	0.3	4.1	0.239	0.159	438°.12	429°.94	52.1	0.143
3	N	1.6	7.4	0.679	0.509	455°.62	373°.82	13.97	0.046
4	D	2.0	9.2	0.615	0.410	649°.3	571°.75	19.04	—
5	L	3 3	3.1	0.482	0.361	322°.18	303°.	23.68	0.223
6	L′	4.5	6.6	0.436	0.303	383°.	324°.62	23.68	0.223
7	I	6.2	5.9	0.289	0.185	359°.71	332°.29	33.5	0 088
8	C	8.4	2.5	0.207	0.161	418°.	415°.5	66.91	0.130
9	B	10.5	6.6	0.420	0.288	584°.13	517°.5	39.17	0.285
10	M	11.1	7.1	0.429	0.286	534°.	417°.	30.97	0.300
11	E	13.3	7.2	0.410	0.263	382°.63	419°.6	27.49	0.102
12	J	14.4	6.5	0.372	0.236	472°.81	295°.82	37.67	0.202
13	F	15.9	4.2	0.307	0.214	—	393°.33	38 06	0.120
14	A	18.5	5.0	0.458	0.351	604°.62	523°.81	31.89	0.119
15	G	22.8	9.7	0.646	0.426	—	—	23.11	0 148

conditions. Some notes are added to show the relative value of the different experiments in respect to precision and other necessary items.

Table XXI. contains results of experiments made with a water-tube boiler, which, while it was not the most economical boiler of that type tested at the Centennial Exhibition, is very largely in use, so that records of its performance are

Table XXI.

Tests of Babcock & Wilcox Water-Tube Boilers, at Different Rates of Combustion.

Item.	Natural Draft.								Forced Draft.
	1	2	3	4	5	6	7	8	9
Heating surface, sq. ft.	2807.16	1558	1676.32	1558	2122	4080	1592	1676.32	2807.16
Grate surface, "	70	30	44.5	30	50.75	103	46	44.5	70
Ratio of heating to grate surface	40.1	51 9	37.67	51.9	41.81	39.61	34.6	37.67	40.1
Temperature of feed water.	153°	204°.8	63°.98	205°	165°.8	110°59	150°	57°.6	160°
Temperature of flue	—	—	—	—	326°	453°23	467°	472°.81	—
Pressure of steam, lbs. per sq. in. above atmosphere.	75	76.3	70	81.5	62.5	71.63	70	70	85
Per cent. of refuse	25.5	17.12	10.997	16.18	13.708	14.94	21.43	7.842	26.
Lbs. of combustible per hour.	Total	617	367	396	407	568	1301	563	623	1247
	℔□ grate*	8.81	12.23	8.89	13.58	11.22	12.63	12.24	14.00	17.82
	℔□′ heating*	0.226	0.235	0.236	0.261	0.268	0.319	0.354	0.372	0 444
Lbs. of water evaporated per hour, from and at 212°.	Total	6725	3974	4678	4519	6591	14583	6339	6436	11294
	℔□′ grate*	96.07	132.15	105.12	150.63	129.86	141.58	137.81	144.64	161.34
	℔□′ heating *	2.40	2.54	2.79	2.90	3.11	3.57	3.98	3.84	4.02
H. P. developed, at 30 lbs. per hour, from and at 212°	224.2	132.2	155.9	150.6	219.7	486.1	211.3	214.5	376.5
Lbs. of coal ℔ hour per H.P.	3.69	3.35	2.85	3.23	3.00	3.15	3.39	3.15	4.48
" combustible " "	2.75	2.78	2.54	2.70	2 59	2.68	2.67	2.90	3.31
□′ of grate surface " "	0.312	0.227	0.285	0.199	0.231	0.212	0.217	0.207	0.186
" heating " " "	12.52	11.79	10 75	10.34	9.66	8.39	7.53	7.81	7.46
Lbs. of water evaporated from and at 212°	℔ lb. of coal.	8.13	8.96	10.52	9.30	9.99	9.54	8.84	9.52	6.70
	" combust'e	10.91	10.81	11.82	11.10	11.58	11.21	11.25	10.33	9.05
Actual efficiency	0.808	0.801	0.876	0.822	0.858	0.830	0.833	0.765	0.671
Theoretical efficiency	0.938	0.932	0.931	0.921	0.918	0.906	0.882	0.874	0.901
Ratio of actual and theoretical efficiency	0.861	0.859	0.941	0.893	0.934	0.917	0.945	0.876	0.744

* Surface.

more available than those of most other varieties.

Experiments 1 and 9 were made with the same boiler, as were experiments 2 and 4, but in these latter experiments the quality of the steam was not tested, and the feed water was measured with a meter. Experiments 3 and 8 are the Centennial tests. In experiment 5, the quality of the steam was not tested. Table XXII. is intended to show the value of furnace heating-surface in improving the performance of wasteful boilers, and in rendering boilers economical when forced to their utmost capacity. The heating-surface known as a generator attachment, the effect of which has already been illustrated in the Centennial tests, is placed close to the hottest fire and the most highly heated gases of the furnace. The idea of such an attachment is very old, but it is only within a comparatively short time that the manufacturers of these devices have succeeded in rendering them durable. It needs no argument to demonstrate the utility of such an attachment, if experience proves that it does not burn out. The table also shows the economy of extending the heating-surface, or what is the same thing, running a boiler at about half capacity. This is not the usual practice in large establishments, nor is it generally desirable; for the experiments show that the six tubular boilers, experiments 4, 5, 6, could readily be made to do all the work of the 16 cylinder boilers in addition to their reported performance, and with more economy than is obtained by the combination of cylinder and tubular boilers. Experiments 1, 2, 3, Table XXII., were made with the same quality of coal. In experiments 2 and 3 the boilers were forced to their utmost capacity with natural draft, a special effort being made to burn as much coal as pos-

TABLE XXII.

TESTS OF WATER-TUBE, FIRE-TUBE, AND CYLINDER BOILERS.

Item.	1	2	3	4	5	6	7	8	9
	Stead's water-pipe boiler, with water bridge-wall, and coils on sides of furnace.	Cylindrical tubular boilers, with Stead's generator attachment, consisting of water bridge-wall, and coils in furnace and connection chamber.		6 cylindrical tubular, and 16 cylinder boilers. Tubular, 6 feet by 15, 100 tubes, 3 inch. Cylinder boiler, 30 in. by 30 ft.			Three cylinder boilers, 30 inches by 30 feet, with and without Stead's generator attachment.		
		6 feet diameter, 18 feet long, 74 tubes, 4 inches.	6 feet diameter, 21 feet long, 35 tubes, 5 inches.	One tubular boiler.	One cylinder boiler.	Averages and totals for all the boilers.	As originally set.	With water bridge-wall and coils under boilers.	With water bridge-wall, coils under boilers, and in furnace.
Heating surface, boiler...sq. ft.	—	1516.4	1202.6	—	—	—	—	353.4	353.4
" generator attachm't "	—	259.3	213.7	—	—	—	—	232 8	353.1
Heating surface, total....sq. ft.	1989.3	1775.7	1416.3	1319.5	117.8	9801.6	353.4	586.2	706.5
Grate surface	33	33	39	27.75	11	342.5	32	32	32
Ratio of heating to grate surface	60.3	53.8	36.3	47.5	10.7	28.6	11	18.3	22.1
" tube vent "	—	0.170	0.108	0.149	—	—	—	—	—
Temperature of feed water	37°	37°	37°	107°.7	152°.7	130°.2	150°	150°	150°
" flue	621°	438°	564°	319°	494°	406° 3	—	—	—
Pressure of steam, lbs. per sq. in. above atmosphere	67	80	61	70.5	69.4	69.9	88	90	90
Per cent. of refuse	15.6	14.4	13.4	13.3	14.6	14.2	14.6	14.6	14.6
Lbs. of combustible per hour. Total	403	534	555	179	102	2697	176	182	192
Lbs. of combustible per hour. ▱′ grate surface	12.1	16.1	14.2	6.43	9.24	7.88	5.5	5.67	6.
Lbs. of combustible per hour. " heating "	0.204	0.301	0.392	0.135	0.863	0.275	0.498	0.310	0.272
Lbs. of water evaporated per hour, from and at 212°. Total	5337	6187	5332	2370	885	28888	1609	2118	2338
Lbs. of water evaporated per hour, from and at 212°. ▱′ grate surface	162.	187.5	136.7	85.4	80.4	84.3	50.3	66.2	73.1
Lbs. of water evaporated per hour, from and at 212°. " heating "	2.69	3.86	3.76	1.8	7.51	2.95	4.55	3.61	3.31
H. P. developed, at 30 lbs. per hour, from and at 212°	177.9	206.2	177.7	79.	29.5	962.9	53.6	70.6	77.9
Lbs. of coal per hour per H. P.	2.68	3.03	3.61	2.61	4.04	3.26	3.84	3.02	2.89
" combustible " "	3.27	2.59	3.12	2.27	3 44	2.8	3 29	2.57	2.47
□′ of grate surface " "	0.186	0.160	0.219	0.351	0.373	0.356	0.597	0.453	0.411
" heating " " "	11.18	8.61	7.97	16.7	3.99	10.18	6.6	8.3	9.07
Lbs. of water evaporated from and at 212° Per lb. of coal	11.16	9.92	8.32	11.5	7.38	9.19	7.8	9.97	10.39
Lbs. of water evaporated from and at 212° " combustible	13.31	11.59	9.6	13.29	8.64	10.71	9.13	11.67	12.17
Actual efficiency	0.986	0.859	0.711	0.984	0.640	0.793	0.676	0.864	0.901
Theoretical efficiency	0.944	0.901	0.865	0.985	0.714	0.915	0.828	0.901	0.916
Ratio of actual and theoretical efficiency	1.010	0 953	0.822	0.999	0.896	0.867	0.816	0.959	0.984

sible. Boiler, experiment 2, is arched, so that the products of combustion return over the top of the boiler. Boiler, experiment 3, is not arched, and the results show the inferiority of this mode of setting when a boiler is forced. Tubular boilers, experiments 4, 6, are arched, and have fuel economizers in the flues, repre-

Table XXIII.

Tests of Cylindrical Tubular Boilers, at Different Rates of Combustion.

Item.	1	2	3	4	5	6	7
	Four boilers, each 4 feet diameter, 14 feet long, with 60 tubes, 3 inches.	Three boilers, each 5 ft. diameter, 16 feet long, with 80 tubes, 3 inches.	One boiler, 4 feet diameter, 14 feet long, with 49 tubes, 3 inches.	One boiler, 4 feet diameter, 15 feet long, with 36 tubes, 4 inches.	Four boilers each 4 feet diameter, 14 feet long, with 60 tubes, 3 inches.	One boiler, 4 feet diameter, 15 feet long, with 36 tubes, 4 inches.	Three boilers, each 3.33 ft. diameter, 17 ft. long, with 19 tubes, 4 inches.
Heating surface.... .....sq. ft.	2990.8	3372.4	626.74	688.72	2990.8	688.72	1284
Grate " ..... "	64	75	18	14	64	14	58.62
Ratio of heating to grate surface.....	46.73	45.	34.82	49.19	46.73	49.19	21.9
" tube vent "	0.155	0.135	0.112	0.193	0.155	0.193	0.074
Height of boiler above grate.....inch	18.5	20.5	23	28	18.5	28	—
Temperature of feed water.....	153°87	109°	157°91	52°.59	161°55	71°.05	150°
" flue.....	371°73	476°	292°94	331°14	387°72	373°18	543°
Pressure of steam, lbs. ℙ□′ above atmosphere	98.86	41.3	67.42	70.38	87.37	70.67	70
Per cent. of refuse.....	12.07	17.31	3.8	7.24	8.49	6.54	20.84
Lbs. of combustible per hour. { Total.....	282	519	120	138	635	259	640
Per sq. ft. of grate surface.....	4.41	6.91	6.68	9.84	9.90	18.49	10 92
" " heating "	0.094	0.154	0.192	0.200	0.212	0 376	0.499
Lbs. of water evaporated per hour, from and at 212°. { Total.....	2970	6699	1154	1471	5796	2385	6767
Per sq. ft. of grate surface.	46.41	89.32	64.12	105.06	90.56	170.36	115.43
" " heating "	0.99	1.98	1.84	2.13	1.94	3.46	5.27
Horse power developed, at 30 lbs. per hour, from and at 212°.....	99.	223.3	38.5	49.	193.2	79.5	225.6
Lbs. of coal per hour per horse power.....	3.24	2.80	3.25	3.03	3.59	3.49	3.59
" combustible " "	2.85	2.32	3.13	2.81	3.16	3.18	2.84
Sq. ft. of grate surface "	0.646	0.336	0.468	0.286	0.331	0.176	0.260
" heating " "	30.21	15.1	16.29	14.05	15.48	8.66	5.69
Lbs. of water evaporated from and at 212° { Per lb. of coal....	9.25	10.70	9.23	9.90	8.35	8.61	8.36
" " combustible	10.52	12.92	9.60	10.68	9.13	9.21	10.57
Actual efficiency.....	0.777	0.957	0.711	0.791	0.676	0.682	0.783
Theoretical efficiency.....	1.003	0.971	0.950	0.946	0.941	0.872	0.827
Ratio of actual and theoretical efficiency.....	0 775	0.985	0.748	0.836	0.719	0.782	0.946

senting, both in theory and practice, the most economical mode of setting a plain, cylindrical tubular boiler. In experiments 7, 8, 9 the quality of the steam was not tested, and the weight of ashes, not being reported, was assumed as equivalent to the refuse in experiment 5.

Table XXIII. has been prepared to show the performance of cylindrical tubular boilers in practice which represents the average, and which is generally bad.*

Experiments 1 and 5 were made with the same boilers, not arched.

Boilers, experiment 2, were not arched, and the results of this experiment were obtained after resetting the boilers, their original evaporation of water from and at 212° having been 10.01 lbs. per lb. of combustible. The experiment shows that the setting without arch may answer very well for slow combustion.

Experiments 4 and 6 were made with the same boiler, not arched, but having the Jarvis air-setting. Experiment 7, Table XXIII., gives the results of what is called in the report a comparative test with the boilers, experiment 7, Table XXI.; but an examination of the rates of combustion in the two sets of experiments, renders it probable that it would be more accurate, if real comparative results are desired, to compare experiment

*This is exemplified by the common practice of having boilers set by masons who may be good bricklayers, but are not familiar with the laws of combustion; and also by the practice of many boiler makers who set boilers by a fixed rule, with the same grate-bars and flue proportions, regardless of the character of the fuel which is to be used.

TABLE XXIV.

TESTS OF HORIZONTAL FIRE-TUBE MARINE BOILER, AT DIFFERENT RATES OF COMBUSTION. EVAPORATION AT ATMOSPHERIC PRESSURE.

Item.	1 Boiler as built.	2 Grate surface reduced.	3 Eight upper rows of tubes plugged.	4 Ferrules in tubes.	5 Grate surface reduced. Ferrules in tubes. Forced draft.	6 Boiler as built.	7 Upper row of tubes plugged.	8 Six upper rows of tubes plugged.	9 Four upper rows of tubes plugged.
Heating surface.....sq. ft.	949.93	949.93	326.01	949.93	949.93	949.93	860.04	481.99	637.97
Grate " ..... "	36	18	36	36	27	36	36	36	36
Ratio of heating to grate surface	26.4	52.8	9.1	26.4	35.2	26.4	23.9	13.4	17.7
" draft area "	0.128	0.256	0.014	0.100	0.148	0.128	0.114	0.043	0.71
Temperature of feed water.....	62°.1	50°.2	51°.12	74°.08	72°.25	77°.74	72°.17	48°	56°
" fire-room.....	77°.3	65°	55° 04	78°.47	74°.2	94°	93°	48°.45	57°.69
" flue.....	371°	399°	383°	477°	—	600°+	600°+	600°+	600°+
Per cent. of refuse	13.5	20.3	21.3	13.6	22.4	20.3	20.8	21.4	21.
Lbs. of combustible per hour — Total.....	135	152	88	370	513	549	546	310	417
Lbs. of combustible per hour — ▱′ grate surface	3.75	8.43	2.43	10.26	19.00	15.24	15.16	8.62	11.57
Lbs. of combustible per hour — " heating "	0.142	0.160	0.267	0.389	0.540	0 577	0.634	0.643	0 654
Lbs. of water evaporated per hour, from and at 212° — Total.....	1766	1868	1197	4370	6628	6681	6579	3807	5325
Lbs. of water evaporated per hour, from and at 212° — ▱′ grate surface	48.8	103.7	33.1	121.5	245.1	185.4	182.7	106.	147.2
Lbs. of water evaporated per hour, from and at 212° — " heating "	1.85	1.96	3.63	4.60	6.96	7.02	7.64	7.91	8.32
H. P. developed, at 30 lbs. per hour, from and at 212°.....	58.9	62.2	39.9	145.7	220.9	222.7	219.3	126.9	177.5
Lbs. of coal per hour per H. P.	2.71	3.06	2.80	2.94	2.92	3.09	3.14	3.11	2.99
" combustible " "	2.35	2.44	2.21	2.54	2.27	2.47	2.49	2.44	2.35
▱′ of grate surface "	0.612	0.289	0.902	0.247	0 122	0.162	0.164	0.284	0.203
" heating " "	16.13	15.26	8.17	6.52	4 30	4.27	3.92	3.80	3.59
Lbs. of water evaporated from and at 212° — Per lb. of coal...	11.31	9.80	10.70	10.20	11.03	9.70	9.54	9 65	10.09
Lbs. of water evaporated from and at 212° — " combustible	13.08	12.29	13.60	11.81	12.92	12.17	12.05	12.28	12.77
Actual efficiency	0.969	0.910	1.005	0.875	0.957	0.901	0.893	0.910	0 946
Theoretical efficiency	0.977	0.968	0.919	0.866	0.812	0.799	0.780	0.778	0.774
Ratio of actual and theoretical efficiency.....	0.992	0.940	1.099	1.012	1.179	1.134	1.144	1.169	1.222

7, Table XXIII., with experiment 9, Table XXI.

In all the experiments of Tables XXI., XXII., XXIII., where the exceptions have not been noted, the quality of the steam was tested, and the proper corrections have been applied.

Among the boilers that have been noticed in the preceding tables, the only one of the sectional variety which seems to have been designed with any very pronounced idea of the importance of the disposition of the heating-surface is that of experiment 1, Table XXII., and the results of this disposition seem to be very favorable. This boiler differs from most others of the water-tube variety in being composed of horizontal tubes arranged in sections connected at the ends by castings which have the general form of return-bends, and which are provided with hand-holes so as to give access to the interior of the tubes. The boiler is of quite recent design, and, not having come into very extensive use as yet, its true commercial value can only be settled by further experience. It is noticed in this connection, on account of the fact that it seems to possess many characteristics of — together with improvements upon—the only sectional boiler that has has ever been successfully employed for marine purposes, so far as the writer is aware. Reference is made to the Belleville boiler, which is manufactured in France, and which is largely used on

Table XXV.

Tests of Vertical Water-Tube Marine Boiler, at Different Rates of Combustion. Evaporation at Atmospheric Pressure.

Item.	Grate surface and draft area reduced.	Grate surface reduced.	Boiler as built.	Grate surface reduced.	Bars between tubes.			Bars between tubes. Forced draft.	
	1	2	3	4	5	6	7	8	9
Heating surface.....sq. ft.	1264.81	1264.81	1264.81	1364.81	1264.81	1264.81	1264.81	1264 81	1264.81
Grate " ... .. "	18	18	39	24	39	39	39	39	39
Ratio of htg. to grate surface	70.3	70.3	32.4	52.7	32.4	32.4	32.4	32.4	32.4
" draft area " "	0.111	0.308	0.142	0.231	0.100	0.111	0.100	0.111	0.100
Temperature of feed water.	40°	49°.7	58°	48°	75°	72°.17	38°	77°.74	58°
" " fire room..	59°.66	57°	68°.1	57°.8	91°	93°	39°.7	94°	67°.7
" " flue.....	316°	264°	299°	287°	322°	361°	352°	440°	600°+
Per cent. of refuse.....	19.5	25.3	20.4	23.9	20.8	23.8	18.6	20.9	17.3
Lbs. of combustible per hour. { Total.....	180	228	254	292	304	337	369	545	736
℔ □′ grate*..	9.96	12.66	6.51	12.17	7.78	8.84	9.47	13.97	18.87
" heating *	0.142	0.180	0.201	0.231	0.240	0.266	0.292	0.431	0.582
Lbs. of water evaporated per hour, from and at 212° { Total	2396	3028	3442	3957	4517	4738	4908	7298	9804
℔ □′ grate*...	132.5	168.9	87.9	164.7	115.9	121.5	126.	187.6	251.4
" heating *	1.88	2.40	2.71	3.13	3.58	3.75	3.89	5.79	7.75
H. P. developed, at 30 lbs. per hour, from and at 212°	79.9	100.9	114.7	131.9	150.6	157.9	163.6	243.3	326.8
Lbs. of coal ℔ hour, ℔ H.P.	2.80	3.02	2.78	2.91	2.55	2.80	2.77	2.83	2.72
" combustible " "	2.25	2.26	2.21	2.21	2.01	2 13	2.26	2.24	2.25
□ grate surface "	0.225	0.178	0.340	0.182	0.259	0.247	0.238	0.160	0.119
" heating " "	15.84	12.53	11.02	9.59	8.40	8.01	7.73	5.20	3.87
Lbs. of water evaporated from and at 212° { ℔ lb. of coal.	10.72	9.94	10.79	10.31	11.77	10.71	10.83	10.59	11.02
" combusti'e	13.31	13.28	13.55	13.55	14.86	14.06	13.30	13.39	13.32
Actual efficiency.....	0.986	0.984	1.001	1.001	1.101	1.042	0.985	0.992	0.987
Theoretical efficiency.....	0.977	0.957	0.946	0.933	0.930	0.919	0.908	0.850	0.797
Ratio of actual and theoretical efficiency.....	1.009	1.028	1.061	1.101	1.184	1.133	1.085	1.167	1.238

* Surface.

land, and has been employed successfully for several years, according to official reports, in vessels belonging to the French Navy.

In the experiments detailed in Tables XXI., XXII., XXIII. it will be observed that the actual and theoretical efficiency, together with the ratio of these efficiencies, have been given for each experiment, calculated from the data of Table XVI., on the assumption that the evaporation corresponding to an efficiency of unity is 13.5 lbs. of water from and at 212° per lb. of combustible. With ratios so obtained, the effects of the different rates of combustion are equalized, so that the different economical results are strictly comparable, except for the differences in size or quality of fuel. The reader will doubtless understand that the rate of combustion spoken of is referred to the unit of heating-surface. Experiments with boilers are sometimes compared with respect to the rate of combustion per unit of grate-surface or of time; but if the ratios of heating to grate-surface differ in the several boilers, such a comparison determines absolute rather than relative economic values.

The preceding tables cover a wide range of boiler design and management, and are worthy of careful examination by all those who are interested in the use of, or manufacture of, steam generators. The present discussion is far from exhaustive, but it is hoped that it will be suggestive to the reader. In this connection it seems proper to present some

TABLE XXVI.

EXPERIMENTS ILLUSTRATING EFFICENCY OF FURNACE HEATING-SURFACE.

Item.	1	2	2	3	5	6
	Horizontal fire-tube marine boiler.		Vertical water-tube marine boiler.		Horizontal fire-tube marine boiler, Brooklyn Navy Yard.	
	Boiler as built.	Tubes closed	Boiler as built.	Tubes as closed	Boiler as built.	Tubes closed
Heating surface.....sq. ft.	949.93	213.23	1264.81	180.73	150.3	45.5
Grate " ..... "	36	36	39	39	10.8	10.8
Ratio of heating to grate surface.....	26.4	5 92	32.4	4.63	13.9	4 21
Ratio of draft area to grate surface.....	0.128	0.067	0.142	0.068	0 092	0.023
Temperature of feed-water.....	58°	67°.4	58°	67°.4	100°	100°
Temperature of fire-room.....	68°.1	70°.9	68°.1	70°.9	—	—
Temperature of flue.....	510°	—	299°	—	—	—
Pressure of steam, lbs. per sq. in. above atmosphere.	0.	0.	0.	0.	20.	20.
Per cent. of refuse.....	19.6	17.	20.4	16.3	14 7	27.2
Lbs. of combustible per hour. { Total.....	256	259	254	261	101	93
Lbs. of combustible per hour. { Per sq. ft. of grate surface	7.12	7.19	6.50	6.70	9 38	8.57
Lbs. of combustible per hour. { Per sq. ft. of heating surface.....	0.270	1.215	0.201	1.45	0.674	2 035
Lbs. of water evaporated per hour, from and at 212°. { Total.....	3254	2133	3442	2123	919	731
Lbs. of water evaporated per hour, from and at 212°. { Per sq. ft. of grate surface...	90.42	59.3	87.89	54.54	85.2	67.8
Lbs. of water evaporated per hour, from and at 212°. { Per sq. ft. of heating surface.	3.43	10.01	2.71	11.80	6.12	16.08
H. P. developed, at 30 lbs. ¾ hour, from and at 212°	108.5	71.1	114.7	70.8	30.6	24.4
Lbs. of coal per hour, per horse-power.....	2.94	4.39	2.78	4.41	3.86	5.24
Lbs. of combustible per hour, per horse-power.....	2.36	3.64	2.21	3.69	3.30	3.82
Sq. ft. of grate surface "	0.332	0.506	0.340	0.551	0.352	0.443
Sq. ft. of heating surface "	8 76	3.00	11.02	2.55	4 91	1.87
Lbs. of water evaporated from and at 212°. { Per lb. of coal.....	10.22	6.84	10.79	6.81	7.75	5.75
Lbs. of water evaporated from and at 212°. { Per lb. of combustible	12.71	8.24	13.55	8.14	9.08	7.9
Per cent. of evaporation due to furnace htg. surface.	—	64.8	—	60.	—	87.
Actual efficiency.....	0.942	0.610	1.001	0.603	0.672	0.585
Theoretical efficiency.....	0 918	0.640	0.946	0.599	0.769	0.499
Ratio of actual and theoreical efficiency.....	1.026	0.953	1.061	1.006	0.875	1.173

of the maximum evaporative results that have been obtained in accurate trials, with sufficient detail to show the reasons for the same. These results are selected from the "Report of 'The Board of Engineers' on the Experiments tried with the Horizontal Fire-Tube and the Vertical Water-Tube Boilers." Philadelphia: 1868. Table XXIV. gives results obtained with the horizontal fire-tube boiler, and Table XXV. results of experiments with the vertical water-tube boiler, the rates of combustion for each boiler covering about the same rates as obtained in the Centennial boiler tests. In these tables the value of furnace heating-surface is shown most decisively, the highest evaporative ratio of each boiler corresponding to the highest rate of combustion, and all the actual results, with two exceptions in the case of the horizontal fire-tube boiler, exceeding the theoretical results which have been found to agree so well with the practical performance of what may be called good in distinction to the best boilers. The marine boiler of the future ought certainly to be as economical as the marine boiler of 1868. Now, in all the preceding tests with anthracite coal, there is only one boiler whose actual performance exceeds the theoretical result, and that is a sectional boiler, experiment 1, Table XXI., with some very efficient furnace heating-surface. This is a suggestive fact.

The evaporative result, experiment 5, Table XXV., 14.86 lbs. of water from and at 212° per lb. of combustible, is the

Table XXVII.

Experiments Illustrating the Effect of Adding Tubular Heating-Surface to that of the Furnace.

Item.	1	2	3	4	5	6
	Horizontal fire-tube boiler.		Vertical water-tube boiler.		Horizontal fire-tube boiler.	
	Tubes closed.	As built.	Tube spaces closed.	As built.	Tubes closed.	As built.
Relative heating surface.....	1.000	4.455	1.000	6.999	1.000	3.303
Relative evaporation from and at 212° per lb. of combustible..	1.000	1.543	1.000	1.666	1.000	1.149
Relative horse-power developed.	1.000	1.525	1.000	1.621	1.000	1.257

largest obtained by any reliable experiment with which the writer is acquainted. Prof. Rankine reports an experiment ("Manual of the Steam Engine, and Other Prime Movers," 5th edition, p. 298) with the Earl of Dundonald's boiler, using hand-picked Llangennech coal, in which the evaporation was 14.2 lbs.; and in an experiment made by the writer (see "Engineering," XXVIII., 378) with two boilers of the flue and return-tubular marine type, using anthracite coal of exceptional quality, fired by an expert, the evaporation was 14.54 lbs.

The experiments made by the "Board of Engineers" were so varied in character, that it is possible to determine the value of nearly every portion of the heating-surface of the boilers which they tested. Table XXVI. contains four experiments selected from the report of this Board, and two from "Experimental researches in Steam Engineering," illustrating the value of furnace heating-surface. In each pair of experiments all the conditions were approximately the same, except the amount of heating-surface. It will be noticed that the *per cent.* of evaporation due to the furnace heating-surface varies in the several sets of experiments, and this is because the ratio of furnace to total heating-surface also varies. The latter ratio is:

For experiments	1 and 2....	0.224
" "	3 and 4....	0.143
" "	5 and 6....	0.303

The experiments in Table XXVI., which are there arranged to show the value of the furnace heating-surface, also illustrate in a striking manner (see Table XXVII.) the relative inefficiency of the tubular heating-surface, or the comparatively great extension of this heating-surface which is requisite for a slight increase in economy or capacity.

Although the experiments cited in this paper have not been presented in full detail, the most useful items have been selected or calculated from the original data, and only those experiments have been quoted that were sufficiently detailed in the original reports to render it easy to verify every calculated item. Any one who consults for the first time the original reports of experiments, for the purpose of making such a selection, will be surprised to find what a small proportion of the whole number contain all the original data necessary for checking the calculated results. The original data given in a report ought to comprise all the observations and measurements made by the experimenter, so as to enable any one to check his calculations or to extend them if it is desirable. A good illustration of conformity to this principle is to be found in the logs accompanying the report of the Centennial tests, and it is believed that data are there given for checking every item in the tables of results, except that the measurements from which the heating surfaces and draft

OBSERVED DATA.

Number for reference.	Item.	Boiler as originally set.	Boiler with generator attachment.
1	Trial commenced at	6.48 A. M.	6.54 A. M.
2	Trial ended next day, at	6.48 P. M.	6.54 P. M.
3	Lbs. of wood used to start fire	270	270
4	Lbs. of coal put into furnace	21,030	22,830
5	Lbs. of refuse	3,112	3,494
6	Lbs. of feed water (apparent evaporation)	156,205	208,394
7	Index of meter, at commencement of test	11,275	18,398
8	Index of meter, at end of test	13,779	21,731
9	Average steam pressure, lbs per sq. in. above atmosphere	69.5	70
10	Average temperature of feed water	44°	44°
11	Average temperature of flue	536°	419°
12	Average steam pressure, lbs. per sq. in above atmosphere, in tests for quality of steam	70	70
13	Average weight of steam condensed, lbs	10 1	10.3
14	Average temperature of condensed steam	115°	122°
15	Average weight of condensing water, lbs	200	200
16	Average initial temperature of condensing water	44°	44°
17	Final " "	99°	100°
	CALCULATED RESULTS.		
18	Heating-surface of boiler, sq. ft.	1414.4	1414.4
19	Heating-surface of generator attachment "	—	272.4
20	Heating-surface total "	1414.4	1686.8
21	Grate surface "	33	33
22	Tube cross-section "	4.86	4.86
23	Chimney cross-section "	3.53	3.53
24	Ratio of heating to grate-surface	42.86	51.12
25	Ratio of tube cross-section to grate-surface	0.147	0.147
26	Ratio of chimney cross-section to grate-surface	0.107	0.107
27	Duration of test, hours	36	36
28	Total weight of coal, including wood, lbs	21,138	22,938
29	Total weight of combustible, lbs	18,026	19,444
30	Per cent of refuse	14.6	15.2
31	Quality of steam compared with saturated steam (= unity)	0.9942	0.9991
32	Actual evaporation, from temperature of feed, at observed steam pressure, lbs	155,294	208,198
33	Actual evaporation from and at 212°, lbs	187,163	251,504
34	Lbs. of coal per hour — Total	587	637
35	Lbs. of coal per hour — Per sq. ft. of grate-surface	17.8	19.3
36	Lbs. of coal per hour — Per sq. ft. of heating-surface	0.415	0.378
37	Lbs. of combustible per hour. — Total	500	540
38	Lbs. of combustible per hour. — Per sq. ft. of grate-surface	15.2	16.4
39	Lbs. of combustible per hour. — Per sq. ft. of heating-surface	0.354	0 320
40	Lbs. of water evaporated per hour, from temperature of feed, at actual pressure. — Total	4314	5783
41	Lbs. of water evaporated per hour, from temperature of feed, at actual pressure. — Per sq. ft. of grate-surface	130.72	175.25
42	Lbs. of water evaporated per hour, from temperature of feed, at actual pressure. — Per sq. ft. of heating-surface	3.05	3.43
43	Lbs of water evaporated per hour, from and at 212°. — Total	5211	6986
44	Lbs of water evaporated per hour, from and at 212°. — Per sq. ft. of grate-surface	157.91	211.7
45	Lbs of water evaporated per hour, from and at 212°. — Per sq. ft. of heating-surface	3.68	4.14
46	Horse-power developed, at rating of 30 lbs. of water evaporated per hour, from and at 212° per horse-power	173.7	232.9
47	Lbs. of coal per hour per horse-power	3.38	2.74
48	Lbs. of combustible per hour per horse-power	2.88	2.32
49	Sq. ft. of grate-surface per horse-power	0.190	0.142
50	Sq. ft. of heating-surface "	8.14	7.24
51	Lbs. of water evaporated at actual pressure from temperature of feed. — Per lb. of coal	7.35	9.08
52	Lbs. of water evaporated at actual pressure from temperature of feed. — Per lb. of combustible.	8.62	10.71
53	Lbs. of water evaporated from and at 212°. — Per lb. of coal	8 87	10.97
54	Lbs. of water evaporated from and at 212°. — Per lb. of combustible	10.41	12.94
55	Relative heating-surface	1.000	1.193
56	Relative evaporation from and at 212°, per lb. of combustible	1.000	1.242
57	Actual efficiency	0.771	0.958
58	Theoretical efficiency	0.882	0.897
59	Ratio of actual and theoretical efficiency	0.874	1.068

areas were calculated have been omitted. It may not be amiss to conclude this paper with a report of a boiler test, detailing all the observations and measurements, with the exception of the log from which totals and averages have been computed. The observed data from which the calculations have been made are distinguished by italics. It will be seen that there are some important observations necessary for the calculation of results, and others, perhaps quite as important, which are not used in calculation, but which may be valuable for purposes of comparison, or to enable others to extend the calculations. After what has been said in regard to the value of furnace heating-surface, no excuse will be necessary for selecting an example which shows the effect of adding such surface to a boiler.

TEST OF A HORIZONTAL TUBULAR BOILER, AS ORIGINALLY SET, AND AFTER THE ADDITION OF STEAD'S GENERATOR ATTACHMENT.

MEASUREMENTS, &c.

One cylindrical tubular boiler, *diameter of shell, 6ft.; length, 18ft.; with 64 tubes, 4 inches outside diameter*, and with steam dome 3ft. in diameter and 4ft. high. Boiler set in brickwork, without arch over top, the products of combustion passing from the front-connection through a short flue into an iron smoke-stack (which is connected with the flue of another similar boiler), *3ft. in diameter*, and 56.5ft. in height above the grate. *Furnace is 6ft. wide, and 5.5ft. long. One-half of the shell of the boiler is exposed to flame and heated gases, $\frac{7}{10}$ of the back tube-head and all of the front tube-head.* Boiler is set 28 inches above grate. *Generator attachment consists of bridge-wall drum, diameter*, 17 *inches; length*, 7 *feet; one-half exposed; side coils*, 2 *pipes*, 3*in. by* $5\frac{1}{2}$*ft.; 6 pipes*, 3 *in. by* 8*ft.; 2 pipes*, 3*in. by* 9*ft.; and* 8 *return bends*, 3 *in.; bottom and back coils*, 12 *pipes*, 3*in. by* 9*ft.; 6 pipes*, 3*in. by* 5*ft.; and* 24 *return bends*, 3*in.; furnace arch, containing* 15*ft. of* 2*-in. pipe, and three headers, each a piece of* 4*-in. pipe* 1*ft. long.*

The test was conducted by hauling the fire from the furnace, starting a fresh fire with dry wood, which was weighed, and was charged as $\frac{4}{10}$ of so much coal. All coal put into the furnace was weighed, and at the conclusion of the trial, the fire, which had been allowed to burn down, was hauled, and the contents of the furnace and ash-pit were charged as refuse. The coal used was Lehigh anthracite, egg size, and the test was made with damper open, but without any special effort to force the fire. The general feed connection of the boiler was broken, the blow-off pipe was blanked, and an independent feed pipe was attached to the boiler and connected with a steam pump, which drew its supply from two tanks placed on platform scales. The feed water, before entering these tanks, passed through a 2-inch Worthington meter. A pyrometer was placed in the front-connection of the boiler, and the steam gauge was compared with a standard gauge before commencing the trial. The quality of the steam generated by the boiler was tested hourly by condensing a small portion in a surface condenser, and noting the pressure of the steam before condensation, its weight and temperature after condensation, and the weight, initial and final temperatures of the condensing water. Hourly observations were taken of steam pressure, feed temperature, flue temperature, and index of meter.

M. G. TISSINDIER has described to the Paris Academy of Science his new electrical motor for balloons. It consists of a screw propeller with two helicoidal blades nearly 10ft. in diameter, a Siemens dynamo-electrical machine of new design, and a light bichromate of potash battery. It is intended to propel an elongated balloon of about 1000 cubic yards capacity. The frame of the screw propeller weighs 15½lb., is stretched with silk varnished with india-rubber lacquer, and kept taut by steel wire stretchers. The dynamo-electric machine has four electro-magnets in the circuit, and frame parts are of cast steel, so as to bring the weight down to 121 lbs. It drives the screw by gear, which reduces the speed in the proportion of 10 to 1; thus, if the coil makes 1200 revolutions a minute the screw makes 120. It gives out 220 foot-pounds per second with a useful effect of 55 per cent. The bichromate battery gives a better yield than accumulators of the same weight. It consists of an element divided into four series and arranged in tension. The element consists of an ebonite cell holding four litres—or 0.88 gallon—and containing ten plates of zinc and eleven cakes of retort carbon, arranged alternately. The immersed surface of the zinc is one-third that of the carbons. This battery, charged with a highly concentrated and very acid solution, is constant for two hours. The liquid becomes heated as it is impoverished, and the duration of activity may be prolonged by the addition of chromic acid.

THE SIX GATEWAYS OF KNOWLEDGE.*

From "Nature."

I THANK you most warmly for the honor you have done me in electing me to be your president. I value the honor very highly; but when I look at the list of distinguished men who have preceded me in the office, I feel alarmed at the responsibility I have undertaken. A very pleasing duty, however, has been already performed in the interesting and not onerous function we have now gone through. I would gladly speak on the several subjects, for merit in the study of which these prizes have been awarded; but I am afraid that if I were to do so, it would be more for my own gratification than for your pleasure and profit, and I feel that I shall best consult your wishes in passing on at once to the subject of the address which it becomes my duty to give.

The title of the subject upon which I am going to speak this evening might be —if I were asked to give it a title—"The Six Gateways of Knowledge." I feel that the subject I am about to bring before you is closely connected with the studies for which the several prizes have been given. The question I am going to ask you to think of is: What are the means by which the human mind acquires knowledge of external matter?

John Bunyan likens the human soul to a citadel on a hill, self-contained, having no means of communication with the outer world, except by five gates—Eye Gate, Ear Gate, Mouth Gate, Nose Gate, and Feel Gate. Bunyan clearly was in want of a word here. He uses "feel" in the sense of "touch," a designation which to this day is so commonly used that I can scarcely accuse it of being incorrect. At the same time, the more correct and distinct designation undoubtedly is, the sense of touch. The late Dr. George Wilson, first Professor of Technology in the University of Edinburgh, gave, some time before his death, a beautiful little book under the title of "The Five Gateways of Knowledge," in which he quotes John Bunyan in the manner I have indicated to you. But I have said *six* gateways of knowledge, and I must endeavor to justify this saying. I am going to try to prove to you that we have six senses—that if we are to number the senses at all we must make them six.

The only census of the senses, so far as I am aware, that ever made them more than five before was the Irishman's reckoning of seven senses. I presume the Irishman's seventh sense was common sense; and I believe that the large possession of that virtue by my countrymen —I speak as an Irishman—I say the large possession of the seventh sense, which I believe Irishmen have, and the exercise of it, will do more to alleviate the woes of Ireland than even the removal of the melancholy ocean which surrounds its shores. Still I cannot scientifically see how we can make more than six senses. I shall, however, should time permit, return to this question of a seventh sense, and I shall endeavor to throw out suggestions towards answering the question —Is there, or is there not, a magnetic sense? It is possible that there is, but facts and observations so far give us no evidence that there is a magnetic sense.

The six senses that I intend to explain, so far as I can, this evening, are according to the ordinary enumeration, the sense of sight, the sense of hearing, the sense of smell, the sense of taste, and the sense of touch, divided into two departments. A hundred years ago Dr. Thomas Reid, Professor of Moral Philosophy in the University of Glasgow, pointed out that there was a broad distinction between the sense of roughness or of resistance, which was possessed by the hand, and the sense of heat. Reid's idea has not I think been carried out so much as it deserves. We do not, I believe, find in any of the elementary treatises on natural philosophy, or in the physiologists' writings upon the senses, a distinct reckoning of six senses. We have a great deal of explanation about the muscular sense, and the tactile sense; but we have not a clear and broad distinction of the

* An address at the Midland Institute, Birmingham, October 3, 1883, by Prof. Sir William Thomson, LL.D., F.R.S., President.

sense of touch into two departments, which seems to me to follow from Dr. Thomas Reid's way of explaining the sense of touch, although he does not himself distinctly formulate the distinction I am now going to explain.

The sense of touch, of which the organ commonly considered is the hand, but which is possessed by the whole sensitive surface of the body, is very distinctly a double quality. If I touch any object, I perceive a complication of sensations. I perceive a certain sense of roughness, but I also perceive a very distinct sensation, which is not of roughness, or of smoothness. There are two sensations here, let us try to analyze them. Let me dip my hand into this bowl of hot water. The moment I touch the water, I perceive a very distinct sensation, a sensation of heat. Is that a sensation of roughness, or of smoothness? No. Again, I dip my hand into this basin of iced water. I perceive a very distinct sensation. Is this a sensation of roughness, or of smoothness? No. Is this comparable with that former sensation of heat? I say yes. Although it is opposite, it is comparable with the sensation of heat. I am not going to say that we have two sensations in this department—a sensation of heat, and a sensation of cold. I shall endeavor to explain that the perceptions of heat and of cold are perceptions of different degrees of one and the same quality, but that that quality is markedly different from the sense of roughness. Well now, what is this sense of roughness? It will take me some time to explain it fully, I shall therefore say in advance that it is a sense of force; and I shall tell you in advance, before I justify completely what I have to say, that the six senses, regarding which I wish to give some explanation, are: the sense of sight, the sense of hearing, the sense of taste, the sense of smell, the sense of heat, and the sense of force. The sense of force is the sixth sense; or the senses of heat and of force are the sense of touch divided into two, to complete the census of six that I am endeavoring to demonstrate.

Now I have hinted at a possible seventh sense—a magnetic sense—and though out of the line I propose to follow, and although time is precious, and does not permit much of digression, I wish just to remove the idea that I am in any way suggesting anything towards that wretched superstition of animal magnetism, and table-turning, and spiritualism, and mesmerism, and clairvoyance, and spirit-wrapping, of which we have heard so much. There is no seventh sense of the mystic kind. Clairvoyance, and the like, are the result of bad observation chiefly, somewhat mixed up, however, with the effects of wilful imposture, acting on an innocent, trusting mind. But if there is not a distinct magnetic sense, I say it is a very great wonder that there is not.

Many present know all about magnetism. A very large number of pupils have gained an immense amount of valuable knowledge in various subjects, from the classes carried on nightly within the walls of the Birmingham and Midland Institute; and I can see from the prizes that have been awarded, and that I have just now had the pleasure of distributing for excellence and proficiency in this department, that many have learned of magnetism. I had the pleasure of seeing the class-rooms this morning, and I wished I could be in them in the evening to see the studies as carried on in them every evening. Well now, the study of magnetism is the study of a very recondite subject. We all know a little about the mariner's compass, the needle pointing to the north, and so on; but not many of us have gone far into the subject, and not many of us understand all the recent discoveries in electromagnetism. I could wish, had I the apparatus here, and if you would allow me, to show you an experiment in magnetism. If we had before us a powerful magnet, or say the machine that is giving us this beautiful electric light by which the hall is illuminated, it, serving to excite an electro-magnet, would be one part of our apparatus; the other part would be a piece of copper. Suppose then we had this apparatus, I would show you a very wonderful discovery made by Faraday and worked out admirably by Foucault, an excellent French experimenter. I have said that one part of this apparatus would be a piece of copper, but silver would answer as well. Probably no other metal than copper or silver—certainly no other one, of all the metals that are well known, and obtainable for ordinary experiments—possesses, and no other metal or substance, whether metal-

lic or not, is known to possess, in anything like the same degree as copper and silver, the quality I am now going to call attention to.

The quality I refer to is "electric conductivity," and the result of that quality in the experiment I am now going to describe is, that a piece of copper or a piece of silver, let fall between the poles of a magnet, will fall down slowly as if it were falling through mud. I take this body and let it fall. Many of you here will be able to calculate what fraction of a second it takes to fall one foot. If I took this piece of copper, placed it just above the space between the poles of a powerful electromagnet and let it go, you would see it fall slowly down before you; it would perhaps take a quarter of a minute to fall a few inches.

This experiment was carried out in a most powerful manner by Lord Lindsay (now Lord Crawford), assisted by Mr. Cromwell F. Varley. Both of those eminent men desired to investigate the phenomena of mesmerism, which had been called animal magnetism; and they very earnestly set to work to make a real physical experiment. They asked themselves, Is it conceivable that, if a piece of copper can scarcely move through the air between the poles of an electromagnet, a human being or other living creature placed there would experience no effect? Lord Lindsay got an enormous electromagnet made, so large that the head of any person wishing to try the experiment could get well between the poles, in a region of excessively powerful magnetic force. What was the result of the experiment? If I were to say *nothing!* I should do it scant justice. The result was marvelous, and the marvel is that nothing was perceived. Your head, in a space through which a piece of copper falls as if through mud, perceives nothing. I say this is a very great wonder; but I do not admit, I do not feel, that the investigation of the subject is completed. I cannot think that the quality of matter in space which produces such a prodigious effect upon a piece of metal can be absolutely without any—it is certainly not without any—effect whatever on the matter of a living body; and that it can be absolutely without any *perceptible* effect whatever on the matter of a living body placed there seems to me not proved even yet, although nothing has been found. It is so marvelous that there should be no effect at all, that I do believe and feel that the experiment is worth repeating; and that it is worth examining, whether or not an exceedingly powerful magnetic force has any perceptible effect upon a living vegetable or animal body. I spoke then of a seventh sense. I think it just possible that there may be a magnetic sense. I think it possible that an exceedingly powerful magnetic effect may produce a sensation that we cannot compare with heat or force or any other sensation.

Another question that often occurs is, "Is there an electric sense?" Has any human being a perception of electricity in the air? Well, somewhat similar proposals for experiment might, perhaps, be made with reference to electricity; but there are certain reasons, that would take too long for me to explain, that prevent me from placing the electric force at all in the same category with magnetic force. There would be a surface action that would annul practically the force in the interior, there would be a definite sensation which we could distinctly trace to the sense of touch. Any one putting his hand, or his face, or his hair, in the neighborhood of an electric machine perceives a sensation, and on examining it he finds that there is a current of air blowing, and his hair is attracted; and if he puts his hand too near he finds that there are sparks passing between his hand or face and the machine; so that, before we come to any subtle question of a possible sense of electric force, we have distinct mechanical agencies which give rise to senses of temperature and force; but that this mysterious, wonderful, magnetic force, due, as we know, to rotations of the molecules, could be absolutely without effect—without perceptible effect—on animal economy, seems a very wonderful result, and at all events it is a subject deserving careful investigation. I hope no one will think I am favoring the superstition of mesmerism in what I have said.

I intend to explain a little more fully our perceptions in connection with the double sense of touch—the sense of temperature and the sense of force—should time permit before I conclude. But I must first say something of the other

senses, because if I speak too much about the senses of force and heat no time will be left for any of the others. Well, now, let us think what it is we perceive in the sense of hearing. Acoustics is one of the studies of the Birmingham and Midland Institute, of which we have heard many times this evening. Acoustics is the science of hearing. And what is hearing? Hearing is perceiving something with the ear. What is it we perceive with the ear? It is something we can also perceive without the ear; something that the greatest master of sound, in the poetic and artistic sense of the word at all events, that ever lived—Beethoven—for a great part of his life could not perceive with his ear at all. He was deaf for a great part of his life, and during that period were composed some of his grandest musical compositions, and without the possibility of his ever hearing them by ear himself; for his hearing by ear was gone from him for ever. But he used to stand with a stick pressed against the piano and touching his teeth, and thus he could hear the sounds that he called forth from the instrument. Hence, besides the Ear Gate of John Bunyan, there is another gate or access for the sense of hearing.

What is it that you perceive ordinarily by the ear—that a healthy person, without the loss of any of his natural organs of sense, perceives with his ear, but which can otherwise be perceived, although not so satisfactorily or completely? It is distinctly a sense of varying pressure. When the barometer rises, the pressure on the ear increases; when the barometer falls, that is an indication that the pressure on the ear is diminishing. Well, if the pressure of air were suddenly to increase and diminish, say in the course of a quarter of a minute—suppose in a quarter of a minute the barometer rose one-tenth of an inch and fell again, would you perceive anything? I doubt it; I do not think you would. If the barometer were to rise two inches, or three inches, or four inches, in the course of half a minute, most people would perceive it. I say this as a result of observation, because people going down in a diving bell have exactly the same sensation as they would experience if from some unknown cause the barometer quickly, in the course of half a minute, were to rise five or six inches—far above the greatest height it ever stands at in the open air. Well, now, we have a sense of barometric pressure, but we have not a continued indication that allows us to perceive the difference between the high and low barometer. People living at great altitudes—up several thousand feet above the level of the sea, where the barometer stands several inches lower than at sea-level—feel very much as they would do at the surface of the sea, so far as any sensation of pressure is concerned. Keen mountain air feels different from air in lower places, partly because it is colder and drier, but also because it is less dense, and you must breathe more of it to get the same quantity of oxygen into your lungs to perform those functions which the students of the Institute who study animal physiology—and I understand there are a large number — will perfectly understand. The effect of the air in the lungs—the function it performs—depends chiefly on the oxygen taken in. If the air has only three-quarters of the density it has in our ordinary atmosphere here, then one and one-third times as much must be inhaled, to produce the same oxidizing effect on the blood, and the same general effect in the animal economy; and in that way undoubtedly mountain air has a very different effect on living creatures from the air of the plains. This effect is distinctly perceptible in its relation to health.

But I am wandering from my subject, which is the consideration of the changes of pressure comparable with those that produce sound. A diving bell allows us to perceive a sudden increase of pressure, but not by the ordinary sense of touch. The hand does not perceive the difference between 15 lbs. per square inch pressing in all around, and 17 lbs., or 18 lbs., or 20lbs., or even 30 lbs. per square inch, as it experienced when you go down in a diving bell. If you go down five and a half fathoms in a diving bell, your hand is pressed all round with a force of 30 lbs. to the square inch; but yet you do not perceive any difference in the sense of force, any perception of pressure. What you do perceive is this: behind the tympanum, is a certain cavity filled with air, and a greater pressure on one side of the tympanum than on the other gives rise to a painful sensation and sometimes produces rupture of it in a person going

down in a diving bell suddenly. The remedy for the painful sensation thus experienced, or rather I should say its prevention, is to keep chewing a piece of hard biscuit, or making believe to do so. If you are chewing a hard biscuit, the operation keeps open a certain passage, by which the air pressure gets access to the inside of the tympanum, and balances the outside pressure and thus prevents the painful effect. This painful effect on the ear experienced by going down in a diving bell is simply because a certain piece of tissue is being pressed more on one side than on the other; and when we get such a tremendous force on a delicate thing like the tympanum, we may experience a great deal of pain, and it may be dangerous; indeed it is dangerous, and produces rupture or damage to the tympanum unless means be adopted for obviating the difference in the pressures; but the simple means I have indicated are, I believe, with all ordinarily healthy persons, perfectly successful.

I am afraid we are no nearer, however, to understanding what it is we perceive when we hear. To be short it is simply this: it is exceedingly sudden changes of pressure acting on the tympanum of the ear, through such a short time and with such moderate force as not to hurt it; but to give rise to a very distinct sensation, which is communicated through a train of bones to the auditory nerve. I must merely pass over this; the details are full of interest, but they would occupy us far more than an hour if I entered upon them at all. As soon as we get to the nerves and the bones, we have gone beyond the subject I proposed to speak upon. My subject belongs to physical science — what is called in Scotland Natural Philosophy. Physical science refers to dead matter, and I have gone beyond the range whenever I speak of a living body; but we must speak of a living body in dealing with the senses as the means of perceiving—as the means by which, in John Bunyan's language, the soul in its citadel acquires a knowledge of external matter. The physicist has to think of the organs of sense, merely as he thinks of the microscope; he has nothing to do with physiology. He has a great deal to do with his own eyes and hands, however, and must think of them, if he would understand what he is doing, and wishes to get a reasonable view of the subject, whatever it may be, which is before him in his own department.

Now what is the external object of this internal action of hearing and perceiving sound? The external object is a change of pressure of air. Well, how are we to define a sound simply? It looks a little like a vicious circle, but indeed it is not so, to say it is sound if we call it a sound —if we perceive it is as sound, it *is* sound. Any change of pressure, which is so sudden as to let us perceive it is as sound is a sound. There [giving a sudden clap of the hands]—that is a sound. There is no question about it—nobody will ever ask, Is it a sound or not? It is sound if we hear it. If you do not hear it, it is not to you a sound. That is all I can say to define sound. To explain what it is, I can say, it is change of pressure, and it differs from a gradual change of pressure as seen on the barometer only in being more rapid, so rapid that we perceive it as a sound. If you could perceive by the ear that the barometer has fallen two-tenths of an inch to-day, that would be sound. But nobody hears by his ear that the barometer has fallen, and so he does not perceive the fall as a sound. But the same difference of pressure coming on us suddenly—a fall of the barometer, if by any means it could happen, amounting to a tenth of an inch, and taking place in a thousandth of a second —would affect us quite like sound. A sudden rise of the barometer would produce a sound analogous to what happened when I clapped my hands. What is the difference between a noise and a musical sound? Musical sound is a regular and periodic change of pressure. It is an alternate augmentation and diminution of air pressure, ocurring rapidly enough to be perceived as a sound, and taking place with perfect regularity, period after period. Noises and musical sounds merge into one another. Musical sounds have a possibility at least of sometimes ending in a noise, or tending too much to a noise, to altogether please a fastidious musical ear. All roughness, irregularity, want of regular, smooth periodicity, has the effect of playing out of tune, or of music that is so complicated that it is impossible to say whether it is in tune or not.

But now, with reference to this sense

of sound, there is something I should like to say as to the practical lesson to be drawn from the great mathematical treatises which were placed before the British Association, in the addresses of its president, Prof. Cayley, and of the president of the mathematical and physical section, Prof. Henrici. Both of these professors dwelt on the importance of graphical illustration, and one graphical illustration of Prof. Cayley's address may be adduced in respect of this very quality of sound. In the language of mathematics we have just "one independent variable" to deal with in sound, and that is air pressure. We have not a complication of motions in various directions. We have not the complication that we shall have to think of presently, in connection with the sense of force; complication as to the place of application, and the direction, of the force. We have not the infinite complications we have in some of the other senses, notably smell and taste. We have distinctly only one thing to consider, and that is air pressure or the variation of air pressure. Now when we have one thing that varies, that, in the language of mathematics, is "one independent variable." Do not imagine that mathematics is harsh, and crabbed and repulsive to common sense. It is merely the etherealization of common sense. The function of one independent variable that you have here to deal with is the pressure of air on the tympanum. Well now in a thousand counting houses and business offices in Birmingham and London, and Glasgow, and Manchester, a curve, as Prof. Cayley pointed out, is regularly used to show to the eye a function of one independent variable. The function of one independent variable most important in Liverpool perhaps may be the price of cotton. A curve showing the price of cotton, rising when the price of cotton is high, and sinking when the price of cotton is low, shows all the complicated changes of that independent variable to the eye. And so in the Registrar-General's tables of mortality, we have curves showing the number of deaths from day to day—the painful history of an epidemic, shown in a rising branch, and the long gradual talus in a falling branch of the curve, when the epidemic is overcome, and the normal state of health is again approached. All that is shown to the eye; and one of the most beautiful results of mathematics is the means of showing to the eye the law of variation, however complicated, of one independent variable. But now for what really to me seems a marvel of marvels: think what a complicated thing is the result of an orchestra playing—a hundred instruments and two hundred voices singing in chorus accompanied by the orchestra. Think of the condition of the air, how it is lacerated sometimes in a complicated effect. Think of the smooth gradual increase and diminution of pressure—smooth and gradual, though taking place several hundred times in a second—when a piece of beautiful harmony is heard! Whether, however, it be the single note of the most delicate sound of a flute, or the purest piece of harmony of two voices singing perfectly in tune; or whether it be the crash of an orchestra, and the high notes, sometimes even screechings and tearings of the air, which you may hear fluttering above the sound of the chorus—think of all that, and yet that is not too complicated to be represented by Prof. Cayley, with a piece of chalk in his hand, drawing on the blackboard a single line. A single curve, drawn in the manner of the curve of prices of cotton, describes all that the ear can possibly hear, as the result of the most complicated musical performance. How is one sound more complicated than another? It is simply that in the complicated sound the variations of our one independent variable, pressure of air, are more abrupt, more sudden, less smooth, and less distinctly periodic, than they are in the softer, and purer, and simpler sound. But the superposition of the different effects is really a marvel of marvels; and to think that all the different effects of all the different instruments can be so represented! Think of it in this way. I suppose everybody present knows what a musical score is—you know, at all events, what the notes of a hymn tune look like, and can understand the like for a chorus of voices, and accompanying orchestra—a "score" of a whole page with a line for each instrument, and with perhaps four different lines for four voice parts. Think of how much you have to put down on a page of manuscript or print, to show what the different performers are to do. Think, too, how

much more there is to be done than anything the composer can put on the page. Think of the expression which each player is able to give, and of the difference between a great player on the violin and a person who simply grinds successfully through his part; think, too, of the difference in singing, and of all the expression put into a note or a sequence of notes in singing that cannot be written down. There is, on the written or printed page, a little wedge showing a diminuendo, and a wedge turned the other way showing a crescendo, and that is all that the musician can put on paper to mark the difference of expression which is to be given. Well, now, all that can be represented by a whole page or two pages of orchestral score, as the specification of the sound to be produced in say ten seconds of time, is shown to the eye with perfect clearness by a single curve on a riband of paper a hundred inches long. That to my mind is a wonderful proof of the potency of mathematics. Do not let any student in this Institute be deterred for a moment from the pursuit of mathematical studies by thinking that the great mathematicians get into the realm of four dimensions, where you cannot follow them. Take what Prof. Cayley himself, in his admirable address, which I have already referred to, told us of the beautiful and splendid power of mathematics for etherealizing and illustrating common sense, and you need not be disheartened in your study of mathematics, but may rather be reinvigorated when you think of the power which mathematicians, devoting their whole lives to the study of mathematics, have succeeded in giving to that marvelous science.

The sense of sight may be compared to the sense of sound in this respect. I spoke of the sense of sound being caused by rapid variations of pressure. I had better particularize and say how rapid must be the alternations from greatest pressure to least, and back to greatest, and how frequently must that period occur, to give us the sound of a musical note. If the barometer varies once a minute you would not perceive that as a musical note. But suppose by any mechanical action in the air, you could cause the barometric pressure—the air pressure—to vary much more rapidly. That change of pressure which the barometer is not quick enough to show to the eye, the ear hears as a musical sound if the period recurs twenty times per second. If it recurs twenty, thirty, forty, or fifty times per second, you hear a low note. If the period is gradually accelerated, you hear the low note gradually rising, becoming higher and higher, more and more acute, and if it gets up to 256 periods per second, we have a certain note called C in the ordinary musical notation. I believe I describe it correctly as the low note C, of the tenor voice—the gravest C that can be made by a flute. The note of a two-foot organ pipe open at both ends has 256 periods per second. Go on higher and higher to 512 periods per second, and you have the C above that—the chief C of the soprano voice. Go above that to 1,024, you get an octave higher. You get an octave higher always by doubling the number of vibrations per second, and if you go on till you get up to about 5,000 or 6,000 or 10,000 periods per second, the note becomes so shrill that it ceases to excite the human ear and you do not hear it any longer. The highest note that can be perceived by the human ear seems to be something like 10,000 periods per second. I say "something like," because there is no very definite limit. Some ears cease to hear a note becoming shriller and shriller before other ears cease to hear it; and therefore I can only say in a very general way, that something like 10,000 periods per second, is about the shrillest note the human ear is adapted to hear. We may define musical notes, therefore, as changes of pressure of the air, regularly alternating in periods which lie between 20 and 10,000 per second.

Well now, are there vibrations of thirty or forty or fifty or a hundred thousand or a million of periods per second in air, in elastic solids, or in any matter affecting our sense? We have no evidence of the existence in matter of vibrations of very much greater frequency than 10,000 or 20,000 or 30,000 per second, but we have no reason to deny the possibility of such vibrations existing, and having a large function to perform in nature. But when we get to some degree of frequency that I cannot put figures upon, to something that may be measured in millions, if not in hundred thousands of vibrations per second, we have not merely passed the

limits of the human ear to hear, but we have passed the limits of matter, as known to us, to vibrate. Vibrations transmitted as waves through steel, or air, or water, cannot be more frequent than a certain number, which I cannot now put a figure to, but which, I say, may be reckoned in hundred-thousands or a few millions per second.

But now let us think of light. Light we know to be an influence on the retina of the eye, and through the retina on the optic nerve; an influence dependent on vibrations whose frequency is something between 400 million millions per second and 800 million millions per second. Now we have a vast gap between 400 per second, the sound of a rather high tenor voice, and 400 million millions per second, the number of vibrations corresponding to dull red light—the gravest red light of the prismatic spectrum. Take the middle of the spectrum—yellow light—the period of the vibrations there is in round numbers 500 million millions per second. In violet light we have 800 million millions per second. Beyond that we have something that the eye scarcely perceives—does not perceive at all perhaps—but which I believe it does perceive, though not vividly: we have the ultra violet rays, known to us chiefly by their photographic effect, but known also by many other wonderful experiments, that within the last thirty years have enlarged our knowledge of light to a most marvelous degree. We have invisible rays of light made visible by letting them fall on a certain kind of glass, glass tinged with uranium — that yellowish green glass, sometimes called canary glass or chameleon glass. Uranium glass has a property rendering visible to us invisible rays. You may hold a piece of uranium glass in your hand, illuminated by this electric light, or by a candle, or by gas light, or hold it in the prismatic spectrum of white light, and you see it glowing according to the color of the light which falls upon it; but place it in the spectrum beyond the visible violet end, where without it you see nothing, where a piece of chalk held up seems quite dark, and the uranium glass glows with a mysterious altered color of a beautiful tint, revealing the presence of invisible rays, by converting them into rays of lower period, and so rendering them visible to the eye. The discovery of this property of uranium glass was made by Prof. Stokes, and the name of fluorescence from fluor spar, which he found to have the same property, was given to it. It has since been discovered that fluorescence and phosphorescence are continuous, being extremes of the same phenomenon. I suppose most persons here present know the luminous paint made from sulphides of calcium and other materials, which, after being steeped in light for a certain time, keep on for hours giving out light in the darkness. Persistence in emission of light after the removal of the source, which is the characteristic of those phosphorescent objects, is manifested also, as Edmund Becquerel has proved, by the uranium glass, and thus Stoke's discovery of fluorescence comes to be continuous with the old known phenomenon of phosphorescence, to which attention seems to have been first called scientifically by Robert Boyle about 200 years ago.

There are other rays, that we do not perceive in any of these ways, but that we do perceive by our sense of heat: heat rays as they are commonly called. But in truth all rays that we call light have heating effect. Radiant heat and light are one and indivisible. There are not two things, radiant heat and light: radiant heat is identical with light. Take a black hot kettle into a dark room, and look at it. You do not see it. Hold your face or your hand near it, and you perceive it by what Bunyan would have called Feel Gate; only now we apply the word feeling to other senses as well as Touch. You perceive it before you touch it. You perceive it with the back of your hand, or the front of your hand; you perceive it with your face, yes, and with your eye, but you do not see it. Well, now, must I justify the assertion that it is not light? You say it is not light, and it is not so to you, if you do not see it. There has been a good deal of logic-chopping about the words here; we seem to define in a vicious circle. We may begin by defining light—"It is light if you see it as light; it is not light if you do not see it." To save circumlocution, we shall take things in that way. Radiant heat is light if we see it, it is not light if we do not see it. It is not that there are two things; it is that radiant heat has differences of quality. There are quali-

ties of radiant heat that we can see, and if we see them we call them light; there are qualities of radiant heat we cannot see, and if we cannot see them we do not call them light, but still call them radiant heat: and that on the whole seems to be the best logic for this subject.

By the by, I don't see Logic among the studies of the Birmingham and Midland Institute. Logic is to language and grammar what mathematics is to common sense; logic is etherealized grammar. I hope the advanced student in grammar and Latin and Greek, who needs logic perhaps as much as, perhaps more than, most students of science and modern languages, will advance to logic, and consider logic as the science of using words, to lead him to know exactly what he means by them when he uses them. More ships have been wrecked through bad logic than by bad seamanship. When the captain writes down in his log—I don't mean a pun here, log has nothing to do with logic—the ship's place is so-and-so, he means that it is the most probable position — the position which, according to previous observations, he thinks is the most probable. After that, supposing no sights of sun or stars or land to be had, careful observation of speed and direction shews, by a simple reckoning (called technically the dead reckoning), where the ship is next day. But sailors too often forget that what they put down in the log was not the ship's place, but what to their then knowledge was the most probable position of the ship, and they keep running on as if it was the true position. They forget the meaning of the very words in which they have made their entry in the log, and through that bad logic more ships have been run on the rocks than by any other carelessness or bad seamanship. It is bad logic that leads to trusting to the dead reckoning, in running a course at sea; and it is that bad logic which is the cause of those terribly frequent wrecks; of steamers, otherwise well conducted, in cloudy but perfectly fine weather, running on rocks at the end of a long voyage. To enable you to understand precisely the meaning of your result when you make a note of anything about your own experience or experiments, and to understand precisely the meaning of what you write down, is the province of logic. To arrange your record in such a manner that if you look at it afterwards it will tell you what it is worth, and neither more nor less, is practical logic; and if you exercise that practical knowledge, you will find benefits that are too obvious if you only think of any scientific or practical subject with which you are familiar.

There is danger then of a bad use of words, and hence of bad reasoning upon them, in speaking of light and radiant heat; but if we distinctly define light as that which we consciously perceive as light—without attempting to define consciousness, because we cannot define consciousness any more than we can define free will—we shall be safe. There is no question that you see the thing; if you see it, it is light. Well now, when is radiant heat light? Radiant heat is light when its frequency of vibration is between 400 million millions per second and 800 million millions per second. When its frequency is less than 400 million millions per second it is not light; it is invisible "infra-red" radiant heat. When its frequency is more than 800 million millions per second, it is not light if we cannot see it; it is invisible ultra-violet radiation, truly radiant heat, but it is not so commonly called radiant heat because its heating effect is known rather theoretically than by sensory perception, or thermometric or thermoscopic indications. Observations which have been actually made by Langley and by Abney on radiant heat take us down about three octaves below violet, and we may hope to be brought considerably lower still by future observations. We know at present in all about four octaves—that is from one to two, two to four, four to eight, eight to sixteen, hundred million millions —of radiant heat. One octave of radiant heat is perceptible to the eye as light, the octave from 400 million millions to 800 million millions. I borrow the word octave from music, not in any mystic sense, nor as indicating any relation between harmony of colors and harmony of sound, No relation exists between harmony of sound and harmony of colors. I merely use the word "octave" as a brief expression for any range of frequencies lying within the ratio of one to two. If you double the frequency of a musical note, you raise it an octave: in that sense I use the word for the moment in respect

to light, and in no other sense. Well now, think what a tremendous chasm there is between the 100 million millions per second, which is about the gravest hitherto discovered note of invisible radiant heat, and the 10,000 per second, the greatest number of vibrations in sound. This is an unknown province of science: the investigation of vibrations between those two limits is perhaps one of the most promising provinces of science for the future investigator.

In conclusion, I wish to bring before you the idea that all the senses are related to force. The sense of sound, we have seen, is merely a sense of very rapid changes of air pressure (which is force) on the drum of the ear. I have passed merely by name over the senses of taste and smell. I may say they are chemical senses. Taste common salt and taste sugar—you tell in a moment the difference. The perception of that difference is a perception of chemical quality. Well, there is a subtle molecular influence here, due to the touch of the object, on the tongue or the palate, and producing a sensation which is a very different thing from the ordinarily reckoned sense of touch, in the case now considered, telling only of roughness and of temperature. The most subtle of our senses perhaps is sight; next comes smell and taste. Prof. Stokes recently told me that he would rather look upon taste and smell and sight as being continuous because they are all molecular—they all deal with properties of matter, not in the gross, but molecular actions of matter; he would rather group those three together than he would couple any of them with any of the other senses. It is not necessary, however, for us to reduce all the six senses to one, but I would just point out that they are all related to force. Chemical action is a force, tearing molecules apart, throwing or pushing them together: and our chemical sense or senses may therefore so far at least be regarded as concerned with force. That the senses of smell and taste are related to one another seems obvious; and if physiologists would pardon me, I would suggest that they may, without impropriety, be regarded as extremes of one sense. This at all events can be said of them, they can be compared—which cannot be said of any other two senses. You cannot say that the shape of a cube, or the roughness of a piece of loaf sugar or sandstone, is comparable with the temperature of hot water, or is like the sound of a trumpet, or that the sound of a trumpet is like scarlet, or like a rocket, or like a blue-light signal. There is no comparability between any of these perceptions. But if any one says, "That a piece of cinnamon tastes like its smell," I think he will express something of general experience. The smell and the taste of pepper, nutmeg, cloves, cinnamon, vanilla, apples, strawberries, and other articles of food, particularly spices and fruits, have very marked qualities, in which the taste and the smell seem essentially comparable. It does seem to me, although anatomists distinguish between them, because the sensory organs concerned are different and because they have not discovered a continuity between these organs, we should not be philosophically wrong in saying that smell and taste are extremes of one sense—one kind of perceptivity—a sense of chemical quality materially presented to us.

Now sense of light and sense of heat are very different; but we cannot define the difference. You perceive the heat of a hot kettle—how? By its radiant heat against the face—that is one way. But there is another way, not by radiant heat, of which I shall speak later. You perceive by vision, but still in virtue of radiant heat, a hot body, if illuminated by light, or if hot enough to be self-luminous, red-hot or white-hot, you see it; you can both see a hot body and perceive it by its heat, otherwise than by seeing it. Take a piece of red-hot cinder with the tongs, or a red-hot poker, and study it; carry it into a dark room, and look at it. You see it for a certain time; after a certain time you cease to see it, but you still perceive radiant heat from it. Well now there is radiant heat perceived by the eye and the face and the hands all the time; but it is perceived only by the sense of temperature, when the hot body ceases to be red-hot. There is then, to our senses, an absolute distinction in modes of perception between that which is continuous in the external nature of the thing, namely, radiant heat in its visible and invisible varieties. It operates upon our senses in a way that I cannot ask anatomists to admit to be one and the same in both cases. They cannot now, at all

events, say that there is an absolute continuity between the retina of the eye in its perception of radiant heat as light, and the skin of the hand in its perception of radiant heat as heat. We may come to know more; it may yet appear that there is a continuity, Some of Darwin's sublime speculations may become realities to us; and we may come to recognize a cultivable retina all over the body. We have not done that yet, but Darwin's grand idea occurs as suggesting that there may be an absolute continuity between the perception of radiant heat and by the retina of the eye and its perception by the tissues and nerves concerned in the mere sense of heat. We must be content in the meantime, however, to make a distinction between the senses of light and heat. And indeed it must be remarked that our sense of heat is not excited by radiant heat only, while it is only and essentially radiant heat that gives to the retina the sense of light. Hold your hand under a red-hot poker in a dark room: you perceive it to be hot solely by its radiant heat, and you see it also by its radiant heat. Now place the hand over it: you feel more of heat. Now, in fact, you perceive its heat in three ways —by contact with the heated air which has ascended from the poker, and by radiant heat felt by your sense of heat, and by radiant heat seen as light (the iron being still red-hot). But the sense of heat is the same throughout, and is a certain effect experienced by the tissue, whether it be caused by radiant heat, or by contact with heated particles of the air.

Lastly, there remains—and I am afraid I have already taxed your patience too long—the sense of force. I have been vehemently attacked for asserting this sixth sense. I need not go into the controversy; I need not explain to you the ground on which I have been attacked; I could not in fact, because in reading the attack I have not been able to understand it myself. The only tangible ground of attack, was, that a writer in New York published this theory in 1880. I had quoted Dr. Thomas Reid, without giving a date; his date chances to be 1780 or thereabouts. But physiologists have very strenuously resisted admitting that the sense of roughness is the same as that muscular sense which the metaphysicians who followed Dr. Thomas Reid in the University of Glasgow, taught. It was in the University of Glasgow that I learned the muscular sense, and I have not seen it very distinctly stated elsewhere. What is this "muscular sense"? I press upon the desk before me with my right hand, or I walk forward holding out my hand in the dark, and using this means to feel my way, as a blind man does constantly who finds where he is, and guides himself by the sense of touch. I walk on until I perceive an obstruction by a sense of force in the palm of the hand. How and where do I perceive this sensation? Anatomists will tell you it is felt in the muscles of the arm. Here, then, is a force which I perceive in the muscles of the arm, and the corresponding perceptivity is properly enough called a muscular sense. But now take the tip of your finger and rub a piece of sandstone, or a piece of loaf sugar, or a smooth table. Take a piece of loaf sugar between your finger and thumb, and take a smooth glass between your finger and thumb. You perceive a difference. What is that difference? It is the sense of roughness and smoothness. Physiologists and anatomists have used the word "tactile" sense, to designate it. I confess that this does not convey much to my mind. "Tactile" is merely "of or belonging to touch," and in saying we perceive roughness and smoothness by a tactile sense, we are where we were. We are not enlightened by being told that there is a tactile sense as a department of our sense of touch. But I say the thing thought of is a sense of force. We cannot away with it; it is a sense of forces, of directions of forces, and of places of application of forces. If the places of application of the forces are the palms of the two hands, we perceive accordingly, and know that we pereeive, in the muscles of the arms, effects of large pressures on the palms of the hands. But if the places of application are a hundred little areas on one finger, we still perceive the effect as force. We distinguish between a uniformly distributed force like the force of a piece of smooth glass, and forces distributed over ten or a hundred little areas. And this is the sense of smoothness and roughness. The sense of roughness is therefore a sense of forces, and of places of application of forces, just as the sense of forces in your two hands stretched out

is the sense of forces in places at a distance of six feet apart. Whether the places be at a distance of six feet or at a distance of one hundredth of an inch, it is the sense of forces, and of places of application of forces, and of directions of forces, that we deal with in the sense of touch other than heat. Now anatomists and physiologists have a good right to distinguish between the kind of excitement of tissue in the finger, and the minute nerves of the skin and sub-skin of the finger, by which you perceive roughness and smoothness, in the one case; and of the muscles by which you perceive places of application very distant, in the other. But whether the forces be so near that anatomists cannot distinguish muscles, cannot point out muscles, resisting forces and balancing them—because, remember, when you take a piece of glass in your fingers every bit of pressure of every ten-thousandth of an inch pressed by the glass against the finger is a balanced force—or whether they be far asunder and obviously balanced by the muscles of the two arms, the thing perceived is the same in kind. Anatomists do not show us muscles balancing the individual forces experienced by the small areas of the finger itself, when we touch a piece of smooth glass, or the individual forces in the scores or hundreds of little areas experienced when we touch a piece of rough sugar or rough sandstone; and perhaps it is not by muscles smaller than the muscles of the finger as a whole that the multitudinousness is dealt with; or perhaps, on the other hand, these nerves and tissues are continuous in their qualities with muscles. I go beyond the range of my subject whenever I speak of muscles and nerves; but externally the sense of touch other than heat is the same in all cases—it is the sense of forces and of places of application of forces and of directions of forces. I hope now I have justified the sixth sense; and that you will excuse me for having taxed your patience so long in not having done it in fewer words.

NOTE ON THE OPTICAL FORMULA EXPRESSING THE RELATION OF CONJUGATE DISTANCES, AND ON THE THEORY OF THE STADIA.

By R. S. WOODWARD, C. E.

Contributed to Van Nostrand's Engineering Magazine.

In No. 4, Vol. 30 of this magazine, in an article on "The Theory of Stadia Measurements," by Mr. Arthur Winslow, some doubt is raised as to the correctness and range of applicability of the formula expressing the relation between conjugate distances and the principal focal length of a lens or system of lenses. Some new errors are also added in this article to a system of optics already abounding in limitations and obscurities, and the resulting theory of the stadia is left on a very insecure basis, especially since an appeal is made to experiment to show that the usual formula for this instrument is applicable if the telescope used has the ordinary achromatic objective instead of a single bi-convex lens.

It is desired in this note to show, 1st, that although the formula for conjugate distances as commonly understood is inaccurate, yet, if properly interpreted, this formula is not only approximate, but exact; and, moreover, applies equally without modification to any combination of lenses as well as to a single bi-convex lens: 2d, that the ordinary formula for the stadia instrument if properly understood is exact, whatever may be the number, kind, or disposition of the lenses in the telescope so long as they are properly centered.

The theory of the action of a system of lenses on a ray of light passing through them was first adequately discussed by Gauss in his Dioptrische Untersuchungen, 1840 (see list of references below). So exhaustive was his treatment of the subject that few improvements have since been made. His memoir is a master-

piece of mathematical investigation, and the results derived possess at once great generality and simplicity. It is an unfortunate fact, however, that this theory has not found a place in our English text-books, but instead we have repeated errors and assumptions which lead to results confessedly approximate without showing the degree of approximation, and, moreover, results no less complex than the results of the true theory.

The fundamental assumptions of Gauss's theory of the path of a ray of light traversing a system of lenses are:

1. The bounding surfaces of the media (lenses) through which the light passes are spherical and have their centers of curvature in the same straight line or axis.

2. The inclination, i, of the ray at any point of its path is such that sin i and tan i may be replaced by i.

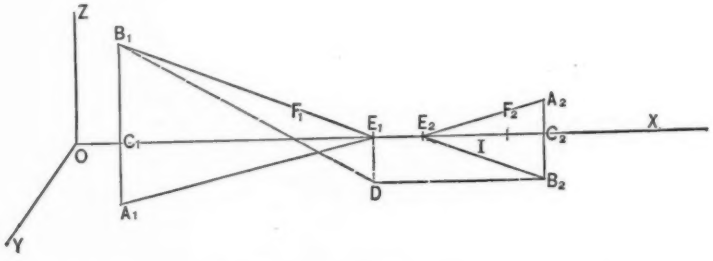
3. The angular width, a, of either spherical surface measured at its center, is such that sin a and tan a may be replaced by a.

Let the centers of curvature of the several bounding surfaces of a system of lenses lie in the axis of X (see diagram). Then whatever the number of lenses or whatever their indices of refraction, there exist always two pairs of points F_1, F_2 called focal points, and E_1, E_2 called principal points. Rays parallel before incidence, and traversing the system of lenses in the direction OX, will be brought to a focus in a plane cutting OX perpendicularly at F_2; conversely, rays parallel before incidence and traversing the system in the opposite direction, will be brought to a focus in a plane cutting OX perpendicularly at F_1. E_1F_1 and E_2F_2 are the principal focal lengths of the system, and in case F_1 and F_2 lie in the same medium, $E_1F_1 = E_2F_2$. These focal and principal points are fixed for any fixed system of lenses. For a system composed of a single double convex or a single double concave lens, the points E_1, E_2 lie somewhat within (not on) the bounding surfaces. For methods of determining the positions of these points in any case, reference may be made to the works cited at the end of this note. These four points afford the following simple relations between the coördinates of an object and the coördinates of its image. Let $x_1\ y_1\ z_1$ be the coördinates of any point of the object, and $x_2\ y_2\ z_2$ the coordinates of the image of this point. Also denote the abscissas of the points E_1, E_2, F_1, F_2 by these same letters respectively. Then when the incident and emergent rays are in the same medium, and f is the principal focal length of the system,

$$(F_1 - x_1)(x_2 - F_2) = f^2 \quad . \quad . \quad (1)$$

$$\frac{1}{E_1 - x_1} + \frac{1}{x_2 - E_2} = \frac{1}{f} \quad . \quad . \quad (2)$$

$$\frac{y_2}{y_1} = \frac{z_2}{z_1} = -\frac{f}{F_1 - x} = -\frac{x_2 - F_2}{f} \qquad (3)$$



Equations (1) and (2) express the relation of conjugate distances according as they are referred to the pair of points F_1, F_2 or E_1, E_2. Equation (3) gives the ratio of corresponding linear dimensions of the object and image. From this equation we have evidently

$$\frac{y_2}{y_1} = \frac{z_2}{z_1} = -\frac{f + x_2 - F_2}{f - x_1 + F_1} = \frac{E_2C_2}{E_1C_1} \quad . \quad (4)$$

This shows that the line B_2E_2 is parallel to B_1E_1, and in connection with (3), gives an easy geometrical construction of the image of any point of an object

when the principal and focal points are given, as indicated by the dotted line in the diagram.

To apply this theory to the case of the stadia instrument put

$$C_1E_1=f_1,\ C_2E_2=f_2$$
$$A_1C_1=z'_1,\ A_2C_2=z'_2$$

Then equations (2) and (4) become

$$\frac{1}{f_1}+\frac{1}{f_2}=\frac{1}{f} \quad . \quad . \quad . \quad . \quad (5)$$

$$\frac{f_1}{f_2}=\frac{z_1}{z_2}=\frac{z'_1}{z'_2}=\frac{z_1+z'_1}{z_2+z'_2} \quad . \quad . \quad (6)$$

Now $z_1+z'_1=A_1B_1$ may represent the space on a stadia target covered by a fixed interval $z_2+z'_2=A_2B_2$ in the plane of the image of the target, the optical axis of the telescope being perpendicular to A_1B_1 at C_1. Put

$$z_1+z'_1=s, \text{ and } z_2+z'_2=s_0.$$

Then (6) gives

$$\frac{1}{f_2}=\frac{1}{f_1}\frac{s}{s_0}$$

which substituted in (5) gives

$$f_1=\frac{f}{s_0}s+f$$

Denote the distance from the center of the instrument I to the target by d, and the distance IE_1 from the outer principal point of the objective to the center of the instrument by c. Then

$$d=f_1+c=\frac{f}{s_0}s+f+c \quad . \quad . \quad (7)$$

This, therefore, is the correct formula for the stadia instrument (for "horizontal sight") whatever the kind of telescope through which the space s on the target is observed. Whether the telescope be composed of one lens or any number of lenses it is only necessary to remember that f and c are distances between fixed points as defined above, and that s_0 is a fixed interval in the plane of the image of the object. Hence $\frac{f}{s_0}$ and $f+c$ are constants for any telescope.

It remains to show how the constants $\frac{f}{s_0}$ and $f+c$ may be determined with precision. Obviously, if two different distances d, and the corresponding spaces s, be observed, these constants can be computed. In all such cases, however, it is desirable to have more than the algebraically sufficient data, and resort to the method of least squares. In applying this method we might consider both the observed quantities d and s subject to error, and hence to correction; but inasmuch as d may be observed with much greater precision than s, the latter only will be considered subject to error. Since the observed quantity must be the absolute term in an observation-equation, we write (7) in the form

$$d\,\frac{s_0}{f}-\frac{s_0}{f}(f+c)-s=v \quad . \quad . \quad (8)$$

in which v is the residual or most probable correction to the observed value of s. The error in s will vary directly as the distance f_1, or with sufficient accuracy as d. Hence the proper weight of the above observation-equation is $\frac{1}{d^2}$. Now put

$$\frac{s_0}{f}=u+\Delta u \text{ and } (f+c)=w+\Delta w$$

in which u and w are approximate values of the left-hand members of these equations respectively, and such that the product of the corrections Δu and Δw may be neglected. Then (8) becomes

$$\Delta u(d-w)-u\Delta w+ud-uw-s=v$$

with weight $\frac{1}{d^2}$

Multiply this by the square root of its weight, and put for brevity,

$$1-\frac{w}{d}=a,\quad \frac{u}{d}=b \text{ and}$$
$$u-\frac{1}{d}(uw+s)=-n$$

Then the observation-equation will be of the type,

$$a\Delta u-b\Delta w-n=\frac{v}{d} \quad . \quad (9)$$

and the normal equations are,

$$\begin{array}{llll} [aa]\,\Delta u-[ab]\,\Delta w-[an]=o \\ -[ab] \quad +[bb] \quad +[bn]=o \end{array} \quad (10)$$

To show the application of these form-

ulas we take the data furnished by Mr. Winslow on p. 319, Vol. 30, No. 4, of this journal. These data and the derived quantities are shown in the following table. The approximate values assumed for u and w are:

d	s	a	b	n	$\frac{v}{d}$
50.0 ft.	0.4855 ft.	0.9700	0.0002000	−0.0000100	−170
100. "	0.9850 "	.9850	1000	000	+437
200. "	1.9850 "	.9925	500	000	+240
300. "	2 9878 "	.9950	333	− 090	−725
400. "	3.9840 "	.9962	250	+ 025	+392
500. "	4.9867 "	.9970	200	− 030	−177

$$u=0.01 \qquad w=1.5 \text{ feet.}$$

The values of the residuals in the last column of the table are expressed in units of the eighth decimal place.

The normal equations are, after multiplying them by 10^8,

$$587260000\Delta u - 42010\Delta w - 1915.6 = 0$$
$$-42010 \quad +5.3636 \quad +0.22975 = 0$$

The values of the unknowns and their probable errors are,

$$\Delta u = +0.00000045 \pm 0.00000208$$
$$\overset{\text{ft.}}{\Delta w} = \overset{\text{ft.}}{-0.0393 \pm 0.0213}$$

Hence

$$\frac{1}{u+\Delta u} = \frac{f}{s_0} = 99.9541 \pm 0.0029$$
$$\overset{\text{ft.}}{w+\Delta w} \quad \overset{\text{ft.}}{f+c} = 1.461 \pm 0.021$$

These results indicate that the values of d and s used as data were carefully observed. They also show that a high degree of precision is attainable with the stadia, as compared with chaining, over rough ground.

List of works giving Gauss's theory of a system of lenses:

1. The original Dioptrische Untersuchungen is contained in Vol. V. of Gauss's works, published by the Royal Society of Göttingen, 1867.

2. A complete translation in French of Gauss's memoir, by M. A. Bravais, may be found in Annales de Chemie et de Physique, Vol. 33, 3d Series, 1851, and also in Liouvilles Journal for 1856.

3. A very clear though incomplete exposition of Gauss's theory is given in Die Haupt und Breun-Puncte eines Linsen Systemes, by Carl Neumann. B. G. Teubuer, Leipzig, 1866.

4. A brief development of the theory is also given by Jamin in Cours de Physique, Vol. 3. Gauthier Villars, Paris, 1879.

STRAIGHTENING HARDENED STEEL.—It is well known that files are not usually drawn after being hardened, and that the hardening frequently springs them out of line. But notwithstanding that the files are made as hard as they can be by heat and cold water, they are readily straightened after being hardened. This operation is performed at once, as soon as the files have been dipped. The files are taken from a bath of melted lead and chilled while red hot in a tank of running water. This immersion for the instant hardens only the surfaces, while the interior is soft and pliant with heat. At this time the file may be straightened by bending over and under bars. By similar means crooks in steel, arbors, reamers, and other long tools may be removed, even after they have been hardened and tempered. A cast steel saw arbor had received an offset or crook in the journal at one end just inside the shoulder. The crook was at the worse end, that next the saw, and although scarcely perceptible to the eye when the arbor was turned on its centers, it was sufficient, when the arbor was in the boxes, to throw the periphery of a two-foot saw considerably out. The arbor at the bearing part was very gradually heated—not enough to change color but to a " black heat." A V-shaped block was placed in a vice bearing against the offset side of the journal, and the vice screwed up. At the third trial the arbor came out perfectly true. A tempered reamer was straightened in the same way, the point at which it was crooked being heated by an alcohol lamp. The heat was sufficient to allow the steel to give, but not enough to start the temper. Steel that has a blue temper only may be straightened by blows with a pony hammer on a smooth, clean anvil, the face of which should be warmed enough to remove the chill.—*Scientific American.*

TESTING MACHINES, THEIR HISTORY, CONSTRUCTION AND USE.

By ARTHUR V. ABBOTT.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

IV.

DEFORMATION.

Upon all materials of a ductile character the effect of the stress is to produce more or less deformation in the size and the shape of the piece. In tension specimens the piece is elongated considerably, and the point at which the fracture occurs is by the flow of the metal drawn down more or less to a conical point. Pieces that are subjected to compression are shortened in length, and by a reversed process are bulged out into a sort of a barrel shape form; while in transverse stress the piece is bent into a U-shaped form. In tension pieces the amount of elongation and the amount of contraction of area are regarded as exceedingly good indications of the value of the material for structural purposes.

ELEVATION OF THE ULTIMATE AND THE ELASTIC LIMIT.

It was first observed by Prof. R. H. Thurston and Commander L. A. Beardsley, U. S. N., independently, that if a ductile material be subjected to a stress beyond the elastic limit, but not beyond its ultimate resistance and then allowed to rest for a definite period of time, a considerable increase of elastic limit and the ultimate resistance may be detected. In other words, the application of stress and the subsequent rest increases the resistance of the material. Table No. 4 gives a number of experiments made by the U. S. Board on specimens of various sizes. Each specimen was subjected to two tests, and the length of time allowed between first and second tests is given in the table. It will thus be seen from the inspection of this table that the ultimate resistance was very largely increased by allowing the piece to rest more or less between the experiments. The cause of this may perhaps be explained by the theory that, as soon as the elastic limit is reached and the metal begins to flow, the molecules, subjected to the force of the stresses, take up new positions with reference to each other. As long as this stress is continued the moving molecules have acquired a certain momentum.. If,

TABLE 4.

Size of bar	Strength in Pounds per Square Inch.		Interval between Tests.	Gain in Strength
	1st Test.	2d Test.		Pr. ct.
1¼	50,825	51,351	1 minute	1
1⅞	48,809	49,110	1 minute	0.6
1¼	49,877	50,614	3 minutes	1.5
1⅜	49,024	49,637	3 minutes	1.3
1½	49,865	50,388	3 minutes	1.0
⅞	49,345	49,993	1 hour	1.3
⅞	49,358	50,219	2 hours	1.7
⅞	49,459	51,362	3 hours	3.8
⅞	49,484	51,546	4 hours	4.2
⅞	49,401	51,561	5 hours	4.3
⅞	49,206	51,996	6 hours	5.6
⅞	50,257	52,886	7 hours	5
⅞	50,013	52,572	8 hours	5
1	51,536	60,631	3 days	17.6
1¼	49,935	58,251	3 days	17
1	49,962	56,207	3 days	12.5
1⅜	49,175	57,635	3 days	17 2
1½	49.267	58,049	3 days	17.8
1⅝	50,143	58,136	3 days	14.1
1¾	49,266	57,263	3 days	16.2
1¾	49,438	57,991	3 days	17.3
1⅞	48,537	54,655	3 days	12.6
2	48,597	57,124	3 days	17.5
1⅜	48,853	57,443	8 days	17.6
1½	50,015	59,047	8 days	18
1⅛	50,474	59,864	18 days	18.6
1⅛	50,178	58,314	18 days	16.1
1⅛	50,165	54,749	18 days	9
1⅝	49,676	59,184	25 days	19.1
1⅝	49,867	55,949	42 days	12.3
1	51,128	60,902	6 months	19.1
1⅛	50,530	59,626	6 months	18.
1¼	49,101	57,877	6 months	17.8
1⅜	48,819	56,885	6 months	16.6
1½	51,838	57,188	6 months	10.3
1⅝	49,144	58,188	6 months	18.3
1¾	48,792	57,403	6 months	17.2
1⅞	49,370	58,880	6 months	19.4
2¼	49,250	58,020	6 months	17.7
2½	47,871	58,976	6 months	22.6
2¾	46,702	54,458	6 months	16.6
3	47,665	57,250	6 months	20

ABSTRACT FROM DETAIL OF TESTS.

	Per cent.		Tests.
Average gain in less than 1 hour.	1.1	..	5
Average gain in less than 8 and over 1 hour.....	3.8	..	8
Average gain in 3 days	16.2	..	10
Average gain in 8 days.....	17.8	..	2
Average gain in over 8 days and less than 43 days.....	15.3	..	5
Average gain in 6 months.....	17.9	..	12

however, the stress be removed and the piece be left to itself, the molecules come to rest and assume new positions with reference to each other, and the forces of cohesion again come into play and give the piece an increase of tenacity.

EFFECT OF MECHANICAL TREATMENT.

The amount of work that is done upon a piece of iron or steel, whether under the hammer or in the rolling mill, plays an important part in the quality of the material. It has been found by experiment that bars of ductile material, which are apparently precisely alike in every respect, except in area of section, do do not give the same elastic or ultimate

TABLE No. 5.

Diameter of bar.	Tensile Strength.	Elastic Limit.	Diameter of bar.	Tensile Strength.	Elastic Limit.	Diameter of bar.	Tensile Strength.	Elastic Limit.
1/4	59,885	—	1 3/8	53,016	35,379	1 13/16	50,969	30,814
3/8	54,090	40,980	"	51,296	31,992	"	50,307	29,767
1/2	62,700	—	"	50,594	34,940	"	48,953	—
"	59,000	—	1 1/2	57,052	38,417	1 7/8	55,803	31,031
"	57,700	—	"	56,505	32,496	"	53,100	32,074
"	55,400	—	"	55,131	33,771	"	52,875	35,641
"	52,275	39,126	"	54,540	—	"	52,505	32,312
5/8	55,450	—	"	55,415	32,869	"	51,459	27,816
"	52,050	—	"	54,354	34,617	"	50,363	—
"	57,660	—	"	54,544	33,027	"	51,039	33,067
3/4	51,546	35,933	"	53,512	—	"	49,744	35,615
7/8	50,630	33,931	"	52,819	34,840	"	48,670	23,250
1	61,727	—	"	52,736	34,901	2.0	60,213	31,441
"	57,363	37,415	"	52,700	35,880	"	52,914	31,198
"	57,807	39,230	"	52,155	27,708	"	49,164	—
"	56,790	36,885	"	51,994	32,054	"	51,684	33,104
"	51,921	31,300	"	51,456	34,591	"	52,127	32,461
"	52,819	32,267	"	51,047	—	"	52,011	34,702
"	51,400	34,600	1 5/8	56,344	35,889	"	51,146	28,567
1 1/8	60,458	37,344	"	57,402	35,701	"	50,000	36,184
"	57,470	31,900	"	56,227	33,207	"	50,171	28,983
"	57,498	41,311	"	54,334	32,163	"	47,812	35,864
"	55,927	37,250	"	53,339	33,540	"	48,249	31,413
"	54,644	34,695	"	53,614	30,664	"	46,151	36,050
"	53,900	26,787	"	52,675	33,745	2 1/16	51,559	—
"	53,035	34,410	"	52,314	29,364	"	49,422	—
"	52,267	32,019	"	52,401	34,012	2 1/8	50,481	—
1 1/4	59,461	36,501	"	51,205	33,318	"	51,225	—
"	57,897	32,469	"	50,970	33,625	"	48,382	30,459
"	55,782	35,596	1 11/16	56,595	38,310	2 3/16	51,666	—
"	56,334	33,921	"	54,114	—	2 1/4	51,530	—
"	55,253	34,784	"	57,789	34,160	"	49,290	32,163
"	53,893	32,712	1 3/4	57,874	—	"	48,898	—
"	53,247	32,520	"	54,410	31,354	"	46,866	28,241
"	53,752	—	"	53,846	36,573	2 1/2	48,475	28,932
"	52,970	32,075	"	55,018	34,283	"	47,428	29,941
"	53,022	—	"	53,264	—	"	47,344	29,758
"	50,040	30,730	"	53,154	35,323	2 3/4	46,446	26,333
1 3/8	58,926	37,548	"	51,509	20,404	3.0	47,761	26,400
"	58,021	32,152	"	50,395	36,254	3 1/4	47,014	24,591
"	54,949	31,030	"	50,547	35,954	3 1/2	47,000	24,961
"	54,277	33,622	"	49,816	31,214	3 3/4	46,667	23,636
"	52,733	34,606	"	50,129	32,271	4.0	46,322	23,430
"	53,557	33,650	1 13/16	56,577	—			
"	52,537	34,469						

TABLE No. 6.—RECTANGULAR BARS.

Number.	Kind of Iron.	Size of Bar.	Stress in Lbs. per Square Inch.	
			Elastic Limit.	Ultimate.
1	Single Refined.	3×1 inches.	29,000	52,470
2	Double "	3×1 "	31,000	53,550
3	Single "	3×1¼ "	27,330	50,410
4	Double "	3×1¼ "	27,170	50,920
5	Single "	3×1 "	28,330	48,700
6	Double "	3×1 "	29,170	51,370
7	Single "	5×1¼ "	24,830	49,240
8	Double "	5×1¼ "	27,170	51,010

TABLE No. 7.

Progress No.	Blow No.	Bar Section.	Specimen.			E. Lim. lbs. □″	Ult. St. lbs. □″	Elong. %	Reduc %	C.
			L′	D″	□″					
A.....	98190	6″×1	1	1×1	1	46000	81000	21	57.75	20.5
B.....	"	"	"	1×.970	.970	50515	82744	20	57.99	
C.....	"	2′×2	"	.980×980	.960	44792	79166	25	58.51	
D.....	"	"	"	980×.612	.600	46647	79966	25	52.42	
Direct...	"	1×1	"	1.002×1.002	1.004	50797	80677	16.5	85.43	
A.....	98204	6×1	"	1.003×.998	1.001	44955	76423	21.75	56.19	15
B.....	"	"	"	1×1.006	1.006	46223	76451	21.75	48.43	
C.....	"	2×2	"	1.007×.990	.997	44133	76981	23	63.39	
D.....	"	"	"	.998×.605	.605	41322	75207	24	39.67	
Direct...	"	1×1	"	1.002×.998	1.000	42000	69250	20	50.30	
" ...	"	"	"	1.×1.	1.	43000	69000	22.2	71.23	
A.....	98221	6×1	"	1.005×.990	.995	43216	72361	24.25	40.14	18
B.....	"	"	"	1.020×.995	1.015	43353	72660	23.	42.37	
C.....	"	2×2	"	1.005×1.005	1.010	42079	70544	27.	53.48	
D.....	"	"	"	1.005×.598	.598	41807	72324	23.	57.41	
Direct...	"	1×1	"	1×1	1.000	43000	72000	21.	71.91	

resistance per square inch. Other things being equal, bars of the smallest cross section give the greatest intensity of ultimate resistance. Table 5 from the report of the U. S. Board to test iron and steel, gives a very complete exposition of the differences in various sized round iron bars.

The following experiments given in Table No. 7 were made at the Cambria Iron Co. during the investigation of the steel for the East River Bridge, to determine the difference between large and small specimens of the same steel. From several blows of steel, containing varying proportions of carbon, three different sized pieces were rolled. One piece was rolled to be two inches square, a second piece was rolled one inch thick and six inches wide, and the third piece was rolled one inch square. The pieces two inches square were set on a planer and two pieces cut out of them. One piece, marked C, in the accompanying table, was cut directly from the center, while a second piece, marked D, was cut from the side. It will thus be seen that the piece C came directly from the center of the large bar, and was taken from the spot where it had been subjected to the least possible amount of mechanical work, and had no rolled skin on it. The piece D came from the side of the bar, and had been subjected to a trifle more mechanical work, and had one surface of rolled skin. The 6×1-inch bar was cut into two parts, marked respectively A and B. By cutting from the side of the bar one piece, marked B, consequently had three surfaces of rolled skin, while A being cut next to it had only two surfaces of rolled skin. The bars marked direct from the rolls were

rolled to one inch square, and had rolled skin on all four sides.

Table No. 8 gives a series of comparative tests between specimens as usually

TABLE No. 8.

	Blow No.	Bar Section.	Specimen. L'	Specimen. D″	Specimen. □″	E. Lim. lbs. □″	Ult. St. lbs. □″	Elong. %	Reduc. %	M. Elas. lbs. □″	C.
				1.002							
	93709	1″×1″	1	1.002	1.004	49004	74203	22.	68.60	28871000	18
		3½×½		1.512							
	"	flat	"	.483	.730	52192	75573	23.	54.38	31111000	18
				1.000							
	93711	1″×1″	"	1.000	1.000	51000	77500	21.	73.95	29411000	23
				1.754							
	"	6″ channel C	"	.447	.784	49489	75893	14.	64.92	29663000	23
				1.385							
	"	" F	"	.336	.507	53254	78895	19.	59.57	26627000	23
				1.766							
	"	" F	"	.436	.770	51948	77922	20.	51.66	29514000	23
				.980							
	93854	1″×1″	"	.980	.960	49200	76780	18.	72.6	31049000	21
		1½″×$\frac{9}{16}$″		1.455							
	"	flat	"	.565	.822	55960	80280	22.4	64.23	29290000	21
				.990							
	93921	1″×1″	"	.990	.980	53058	82899	20.	77.23	30300000	19
		5″×¼″		2.980							
	"	flat	"	.237	.706	56657	87819	21.	62.61	25753000	19
				1.000							
	94187	1″×1″	1	1.000	1.000	52000	81000	19.5	74.30	27808000	25
		7″×½″		7.03							
Full size	"	flat	3	.510	3.585	49512	84240	11.66	65.91	——	25
				1.002							
	94229	1″×1″	1	1.002	1.004	49800	76942	19.75	75.72	27977000	21
		3″×3″		1.178							
	"	angle	"	.373	.439	52392	82004	20.	66.97	27894000	21
				.992							
	94855	1″×1″	"	.992	.984	50813	75477	21.5	72.56	26774000	17
		6″×½″		—							
	"	flat	"	—	—	56833	78484	23.25	63.06	26023000	17
				1.007							
	99767	1″×1″	"	1 007	1.014	49310	76923	22.	69.92	29527000	19
	"	⅝″ round	"	.666	.348	54885	84770	22.5	43.10	23950000	19
				1.000							
	100706	1″×1″	"	.998	.998	52104	81062	20.	71.54	26815000	18
		9″×⅜″		8.950							
Full size	"	flat	"	.370	3.311	53126	76292	29.	49.84	——	18
				1.002							
	101079	1″×1″	"	1.002	1.004	50798	80179	19.	67.69	25384000	18
				1.504							
	"	9″ channel C	"	.508	.764	45812	74607	22.1	54.58	——	18
				1.501							
	"	" F	"	.503	.755	47682	74172	22.6	65.96	——	18
				1.505							
	"	" F	"	.509	.766	48303	73107	29.9	62.01	——	18
				1.000							
	101140	1″×1″	"	1.000	1.000	54000	84000	20.	74.82	2425000	18
		5″×½″		4.854							
Full size	"	flat	"	1.524	7.397	47081	76418	19.4	55.09	30000000	18
				1.000							
	101237	1″×1″	"	1.000	1.010	50485	79208	19.	75.80	26710000	18
		3½″×½″		3.489							
Full size	"	flat	"	.512	1.786	47368	72172	28.	61.82	26200000	18
				1.002							
	104452	1″×1″	"	1.006	1.018	49116	77603	22.	65.26	27000000	17
		6″×¼″		5.980							
Full size	"	flat	2	.260	1.555	47267	79331	20.4	38.26	26000000	17

sent to the testing machine, and pieces cut from the same grade of steel after having undergone rolling into structural shapes. Those marked "1 × 1" were test pieces of steel broken at the Cambria Iron Co's. works in Johnstown. While the piecesmarked as having been cut from variousshapes were test pieces of channels, beams and flats of the same blow, numbered as each of the preceding pieces, but after each steel had been rolled into the desired shapes, the letters "C" and "F" denoting that the piece was cut from the center or flange of the bar.

Another curious fact observed during making these steel tests for the East River Bridge was the fact that the time which elapsed between the rolling of the bar and the experiment in the testing machine had a considerable effect upon the amount of reduction and elongation obtained. Bars which were placed in a testing machine as soon as they were cold were generally found to give a reduction and elongation of not over eighteen to twenty per cent. for elongation, and not over twenty-five to thirty-five of reduction; whereas test pieces cut from the same bar, after having been allowed to lie quietly for some weeks, gave an elongation of from twenty to thirty per cent. and a reduction of from forty to sixty per cent. It would seem that the molecular condition of the bar just from the rolls is exceedingly unsettled, and if the bar be allowed to remain quietly for some time, a process analogous perhaps to that of crystallization takes place, and the molecules have time to arrange themselves in more accommodating positions so as to present a great accommodation to the stresses applied by the testing machine.

UNIFORM SIZE OF TEST PIECE.

It is obvious that some agreement with reference to the standard size for test pieces which is extremely desirable. At the present time experimenters all over this country and Europe are constantly making experiments upon a great variety of materials, and collecting a vast amount of data which can be only partly used, from the fact that the pieces experimented upon are so diverse in character, in chemical constitution, in size, and in the shapes from which they are cut, as to render comparison of various results almost an impossibility. The adoption by investigators of some system regarding the size and dimension of the pieces to be used for experimenting would therefore seem to be a necessity. The following standard sizes, as illustrated in Fig. 30, having been found advantageous by the author, are suggested, not by any means as absolute and unvaried standards, but simply as one step towards the desired end.

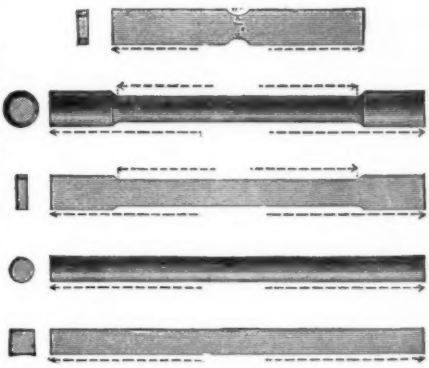


FIG. 30.

For making experiments on steel and iron intended to fulfill bridge and railway specifications pieces direct from the rolls may be used, as indicated in the first two samples.

For sample pieces of squares and rounds, pieces twenty-four inches long may be cut directly from the bar, having as nearly as may be one square inch of cross section. In squares this of course simply means a bar rolled one inch square, while in rounds the piece should be one and one-eighth inch in diameter. Similar observation will apply to flats and boiler plates. In the case of boiler plates, strips should be cut off having a length of twenty-four inches and having, as near as possible, widths so as to give one-fourth, one-half, three-fourths and one inch, or one square inch of cross section. Rounds, squares or flats which cannot readily be obtained in lengths of twenty-four inches, pieces may be prepared, as shown in the second two samples of the above cut. Here the pieces are from sixteen to twenty inches in length, having the center part, for a

TABLE 9.—CHEMICAL ANALYSES OF INGOT IRONS AND STEELS.
ARRANGED ACCORDING TO PER CENT. OF CARBON.

Number.	Carbon.			Sulphur.	Phosphorus.	Silicon.	Manganese.
	Total.	Combined.	Graphitic.				
1	.009	——	——	.009	.084	.163	.020
2	.057	.049	.008	.007	.179	.219	.063
3	.130	.116	.014	.029	.045	.011	.192
4	.234	.230	.004	trace	.039	.084	none
5	.238	——	——	.012	.034	.105	.184
6	.401	——	——	.006	.032	.085	.112
7	.463	——	——	.002	.020	.121	trace
8	.577	.459	.118	.026	.108	.108	.185
9	.639	.627	.012	trace	.007	.154	.050
10	.691	.675	.016	.028	.065	.028	.459
11	.756	.744	.012	.043	.104	.074	.465
12	.806	.793	013	none	.019	.172	.193
13	.873	.833	.040	trace	.015	.134	.046
14	.923	.908	.015	.002	.014	.141	.036
15	.996	.984	.008	none	.019	.157	.245
16	1.072	1.059	.013	"	.022	.162	.252
17	1.121	1.108	.013	"	.023	.206	.269
18	1.154	1.142	.012	"	.020	.204	.282
19	1.328	1.244	.084	"	.017	.246	.262

distance of ten inches, planed or turned so as to give a reduced section. In order to break a piece of uniform size, so as to have the fracture occur exterior to the jaws of the machine, it is necessary to have the test piece sufficiently long, so that the crushing or indenting occasioned by the jaws may be distributed over quite a large area of the test piece, thereby avoiding any danger of crushing or cutting into the piece itself, so as to cause a fracture to occur inside of the jaw. In order to secure this it is essential to have a piece which is sufficiently long so as to present the required length between the jaws and give an additional quality to be placed between the gripping surfaces In order to be certain that no crushing or indenting action occurs, it has been found by experiment best to have at least ten times as much surface in the jaws of the testing machine as there are inches in the cross section in the piece to be tested. If, however, the piece is by machine work so reduced in the center as to present a less cross section than is obtained between the jaws of the machine, this indenting action is entirely avoided, and samples which cannot be obtained in lengths of twenty-four inches or more, may be prepared as above shown. The last figure in the cut indicates the shape of boiler plate test pieces which has previously been used as a standard size by the Government Inspectors of Steam Boilers. The piece is prepared very simply by cutting a strip from a boiler plate and planing or milling a semicircular groove directly in the center of the piece. While it may frequently be necessary to make experiments on pieces of this shape, they are, as has readily been seen from the foregoing experiments, much to be avoided. There is no opportunity for measuring the elastic limit of the piece, as there is no uniform section upon which to take it; also the grooved section of the piece very largely increases the ultimate strength of the material, at the same time decreasing the amount of reduction and entirely precluding the possibility of any stretch measurement. In order to obtain an accurate determination of the elastic limit with a fair estimate of the ultimate strength, elongation and reduction of a material, a length of at least six inches is necessary. In previous experiments it has generally been customary to use a length of eight inches, from the fact that most testing machines have been built of so small capacity that longer pieces were not conveniently handled. This length of eight inches is, however, unfortunate for many reasons. It verges so closely upon the limiting size of the test as to at last raise the question of the accuracy of the result. All of the measurements made

for determining the elastic limit and modulus of elasticity have to be reduced to decimals of the length of the test piece, involving laborious calculation for each reading of the micronometer or vernier gauge. The length of ten inches now proposed as a standard of size of test piece will avoid all computations of this kind, for every reading thus being made in inches, is made in per cent. of the length of the test piece.

Furthermore, the length of ten inches corresponds to two hundred and fifty millimeters, approximately the length of test piece commonly used abroad.

EFFECTS OF CHEMICAL CONSTITUTION.

The resistance of wrought iron to tension varies very marked with its chemical constitution. At present it is quite uncertain to what extent foreign elements in the iron affect its quality.

Variations in the amount of phosphorus and sulphur in wrought iron play a very important part in its physical characteristics, and cannot be too carefully considered in presenting an opinion of the value of the material for structural use.

In steel the effect of variations in chemical constitution is far more marked than it is in the case of iron. The elements, phosphorus, silicon, manganese, carbon and sulphur, all enter into the constitution of most steels in small proportions. A very slight variation in any one of these may make a very marked difference in the quality and value of the steel. The elements phosphorus, silicon, manganese and carbon have been termed by Dr. Dudley as hardening elements, inasmuch as each one of them is capable of conveying to the steel a greater or less degree of hardness. Dr. Dudley, in some experiments presented to the American Institute of Mining Engineers, assumes the hardening effect of phosphorus, silicon, manganese and carbon to be in proportion to the numbers three, five, seven and a-half and fifteen, and reckons the sum of their effects in what he very aptly terms "phosphorus units."

Dr. Dudley concludes that the sum of all these above constituents reckoned in phosphorus units should not exceed thirty to thirty-two units in steels intended for rails. The above figures, thirty-one units, are obtained by adding together the phosphorus percentage, half the per cent. of silicon, one-third that of carbon and one-fifth of manganese. Taken singly, the limit of phosphorus should be placed at $\frac{1}{10}$ of one per cent.; silicon at $\frac{4}{100}$ of a per cent.; manganese at $\frac{3}{10}$ to $\frac{4}{10}$ of a per cent. And carbon from $\frac{25}{100}$ to $\frac{30}{100}$ of a per cent. Any higher proportions than the preceding make the steel too brittle for structural purposes.

The experiments in Tables 9 and 10, made by Prof. Thurston for the Committee on Chemical Research of the United States Board for testing iron and steel, exhibited the chemical constitution with the corresponding physical qualities of ingot irons and steels.

TABLE 10.

Number.	Elongation.	Elastic Limit.	Ultimate Strength.
	Per cent.	Lbs.pr.sq.in.	Lbs.pr.sq.in.
1	29.67	26,500	43,000
2	25.50	34,500	55,000
3	34.33	28,500	52,000
4	20.83	26,000	66,000
5	12.00	49,400	69,700
6	21.67	50,743	71,300
7	20.17	44,000	71,000
8	19 50	47,800	83,100
9	2.75	50,000	94,500
10	3.58	50,500	101,000
11	1.00	65,190	101,400
12	9.75	50,500	112,400
13	8.17	50,500	113,100
14	11.08	51,000	118,900
15	10.08	61,900	122,200
16	7.67	68,100	123,000
17	8.08	68,100	125,500
18	8.67	75,200	130,380
19	7.33	75,300	135,300

A gradual increase in tensile strength and elastic limit may be observed as the proportion of carbon is increased. The quality of the metal isusually fixed by the proportion of carbon but it is also varied to a large extent by the elements, silicon and manganese, as well as by the amount of phosphorus. Prof. Thurston has given the following formula, by means of which a very fair estimate of the strength of steel may be obtained when the proportion of carbon is known: $T=60,000+70,000\ C$. T is the tensile strength in pounds per square inch, and C is the percentage of carbon for annealed samples, and $T=50,000+60,000\ C$. As illustrating this excess

Prof. Thurston has made the following experiments :

TABLE 11.

Carbon.	Tensile Strength—Lbs. per sq. in.	
Per cent.	By Test.	By Calculation.
0.53	79,062	81,740
0.65	93,404	88,940
0.80	99,538	98,060
0.87	106,579	102,020
1.01	109,209	110,300
1 09	116,394	113,480

The preceding examples illustrate very clearly the importance of the chemical constitution, and in all specifications for building materials, whether of iron or steel, the chemical constitution of the metal should be required by the engineer or the architect. It is very true that the knowledge of the engineer is not supposed to be that of the manufacturer, and it would be highly unreasonable for the engineer to prescribe to the manufacturer exactly what formula he should use to obtain the material wished for. At the same time a clause inserted under the head of tests in specifications, requiring a chemical analysis of every melt of steel and frequent analyses of wrought iron, would add very largely to the amount of knowledge obtained of the material to be used, to say nothing of the immense advantage which would accrue, both to the manufacturer, to the engineer, and to the general scientific community, by a correlation between the physical tests and the chemical constituents. While the manufacturer should be allowed a wide margin of chemical constitution, it would be well in specifications, especially those designed for steel work, to prescribe limits for the elements of manganese, carbon, phosphorus and silicon, which the manufacturer should not be allowed to transcend. For it is very possible to make a steel which may come up to a liberal specification and at the time be in many respects unfit for use in a bridge or a building, and in order to avoid difficulties of this kind, limiting maximum and minimum values to the proportions of carbon, phosphorus, manganese and silicon should be assigned in the specifications as well as the maximum and minimum values for elastic limit, tensile strength, reduction and elongation.

WORK DONE IN TESTING.

One of the most important qualities of the material is its resilience or power of resisting shock. This quality is measured by the mechanical work done during the processes of testing. Until recently this quality has been rather overlooked by engineers, but at the present time is demanding more and more attention. The mechanical work done upon a piece tested in tension is most readily obtained by the autographic method, for it is simply the area of the curve enclosed between the axis of X, the curved line given by the test of the piece and the bounding ordinate parallel to the axis of Y. It will thus be seen that the tensile strength, together with the elongation of the piece, are factors in its resilience, so that a piece very stiff and brittle, while it might have an exceedingly high tensile strength, would, having very little elongation, give a very low resilience, and again, softer material having an exceedingly low tensile strength, but a very large amount of elongation, might err on the other side and give equally unfavorable results.

Practical experience has shown that the quality demanded in our bridges, roofs and other structures, is the power of resisting sudden shocks and jars due to the work to which they are subjected, and this power of resisting shock is by far the most important one. A piece of tool steel, while exceedingly strong, will, under a suddenly applied stress, snap like a piece of brittle glass, while the weaker and more resilient structural steel will, under a suddenly applied load, stretch like a piece of india-rubber and come back again to its normal position. While the amount of work done in breaking a test piece is an exceedingly valuable and important characteristic of amount of work up to the elastic limit, is by far the most valuable. And this quantity may be readily calculated by taking the elongation at the elastic limit and multiplying it by half the elastic limit in pounds per square inch. Assuming Hook's Law to be true, this gives the value of the triangle included by the line whose equation is $Y=ax$, and may be as-

sumed to be very accurately the measure of the resilience of the piece up to the elastic limit.

EFFECT OF TEMPERATURE.

As a result of a mechanical work done on the piece by a machine, and of the flowing of the molecules of the metal, the piece gradually becomes warm, so that if the testing machine is very rapidly worked, and the bar is comparatively small, the ends near the fracture may at the end of the experiment become so hot as to be most unbearable to the hand. Probably this elevation of the temperature during the experiment has some effect upon the ultimate resistance, for unquestionably an elevation of the temperature causes the flow of the metal to take place with slightly increased facility. Yet in ordinary experiments this elevation of the temperature is so slight as to produce no sensible effect upon the test piece. Some experimenters have gone so far as to carefully make a thermometrical measurement of the heat produced in this way. While all possible commendation should be given to accuracy and care in making observations, it seems that examinations of this kind are hardly worth the amount of expenditure and trouble that they cause.

That the variation of temperature produces some effect upon the tensile strength of iron and steel is a well understood fact.

From a recent number of the *London Engineering*, a synopsis of some German experiments is obtained. The resistance of the materials at zero centigrade is taken at 100, and that of other temperatures in the proper proportional part of that number, Table 12.

TABLE 12.

Temperature.		Fibrous Iron.	Fine Grained Iron.	Bessemer Steel.
Cent.	Fahr.			
0°	32°	100	100	100
100	212	100	100	100
200	392	95	100	100
300	572	90	97	94
500	932	38	44	34
700	1,292	16	23	18
900	1,652	6	12	9
1,000	1,832	4	7	7

Sir William Fairbairn gives the following as the results of numerous experiments made upon specimens of plate and rivet iron at different temperatures, Tables 13 and 14.

TABLE 13.—EXPERIMENTS ON PLATE IRON.

Temperature, Fahrenheit.	Breaking weight in lbs. per. sq. in.	Stress in Reference to Fibre.
0°	49,009	With.
60	40,357	Across.
60	43,406	Across.
60	50,219	With.
110	44,160	Across.
112	42,088	With.
120	40,625	With.
212	39,935	With.
212	45,680	Across.
212	49,500	With.
270	44,020	With.
340	49,968	With.
340	42,088	Across.
395	46,086	With.
Scarcely red	38,032	Across.
Dull red,	30,513	Across.

TABLE 14.—RIVET IRON.

Temperature. Fahr.	Breaking weight in lbs. per sq. in.	Temperature. Fahr.	Breaking weight in lbs. per sq. in.
−30°	63,239	250	82,174
+60	61,971	270	83,098
66	63,661	310	80,570
114	70,845	325	87,522
212	82,676	415	81,830
212	74,153	435	86,056
212	80,985	Red heat.	36,076

From these tables it will be observed that between the ordinary variation and temperature there is little or no variation of the strength of iron or steel. That many accidents occur from the breakage of railroad rails, tie rods, axles, and many other parts of our common structure during cold and frosty weather, is beyond question; but these failures must be attributed not to a decrease in actual strength of the metal, but to exterior circumstances. Under severe cold of a winter's night the road bed enveloping the track of the railway may become frozen exceedingly hard, and to the passage of the moving train present a structure which is firm and unyielding as that of the most solid granite. Thus the

blow struck by the engine driver against a projecting rail end is much more severe on a cold and frosty day than it is on a warm and sunny one, so that the possible breakage of the rail under circumstances of this kind may be attributed, not to a decrease in the strength of the iron, but to exterior circumstances.

CAST IRON TESTS.

The investigator in making experiments on cast iron is obliged to exercise more care than in experiments on almost any other material. Cast iron is of such an unyielding and crystalline nature, that unless care is taken in setting the piece in the testing machine the results are almost certain to be vitiated by the presence of lateral stresses. Again, unless the piece is prepared in some manner by turning and planing at the center, so as to give a reduced section, there is great danger that the jaws of the testing machine will not grip the piece sufficiently tightly so as to avoid slipping.

If the piece should be taken direct from the sand, without any machining or planing, it becomes quite a difficult matter to get an accurate measurement upon which to calculate the area of the piece, for the outside of the specimen contains a large quantity of sand, which penetrates to a depth of one or two hundredths of an inch, so as to almost preclude the possibility of making accurate measurements.

The effect of remelting on the strength of cast iron is well exemplified by the experiments in Tables 15 and 16.

TABLE 15.

	Lbs. per sq. in.
First melting	14000
2d "	22900
3d "	30229
4th "	35786

TABLE 16.

Time of fusion.	Lbs. per sq. in.
½ hour	17843
1 "	20127
1½ "	24387
2 "	34496

The accompanying table gives a fair average of the results to be generally obtained from tension tests on cast iron:

Good pig iron from 15,000 to 20,000 lbs. per square inch.

Tough cast iron from 18,000 to 24,000 lbs. per square inch.

Hard cast iron from 20,000 to 28,000 lbs. per square inch.

Gun-metal from 25,000 to 32,000 lbs. per square inch.

These are the averages that have been obtained from a large number of miscellaneous irons obtained from various foundries all over the country. Here and there will be found an iron that either exceeds or falls below the preceding averages, as an example of which may be mentioned a phenomenal one sent to the author to be tested by the author within the past year from the foundry of Mr. Gridley, at Warsaw, N. Y. This piece, of pig iron unrefined stood over 40,000 lbs. per square inch.

CEMENT TESTING.

Next to iron and steel, probably the materials which are most subjected to experiment, are the various cements and concretes used for all architectural purposes. Among architects and engineers it is very customary upon buying a lot of cement to take small samples from several of the barrels in each cargo, and after mixing them up and pressing them into a mold, to break the sample by tension, and to judge of the quality of the cement by the results thus obtained.

In making cement tests the following precaution should be observed:

First, the relative quantity of cement and water should be carefully measured, preferably by weighing out the necessary amount of each.

Second, the cement and the water should be carefully and thoroughly incorporated so as to make a mixture which is perfectly uniform in every respect. This is best accomplished by placing the cement on a plate of glass, and slowly pouring the water on it while the mass is being stirred and rubbed by means of a towel.

Third, after the mixture is completed, the cement should be pressed into the mold designed to form the briquette with a perfectly steady and uniform pressure. This is best accomplished by arranging the mold so that it may be filled with cement, then subjected by means of a press to an amount of force that can be definitely weighed.

Fourth, the length of time elapsing between the mixing of the cement and the breaking of the sample should be accurately noted.

Fifth, the temperature of the room in which the samples are kept between the mixing and the breaking, should be maintained as nearly uniform as may be, and preferably should be kept at from 60 to 70 degrees Fahrenheit.

Sixth, the fineness of the grinding of the cement should be carefully noted. It has been customary among English and American experimenters to weigh out a portion of the cement to be tested, and sift it through a sieve containing 2,500 meshes per square inch. The fineness of the cement is expressed by the per cent. of the amount which will pass through the measures of the sieve.

Seventh, the hydraulic properties of the cement are best ascertained by mixing a sample to a requisite quantity of water, and then testing it in two ways:

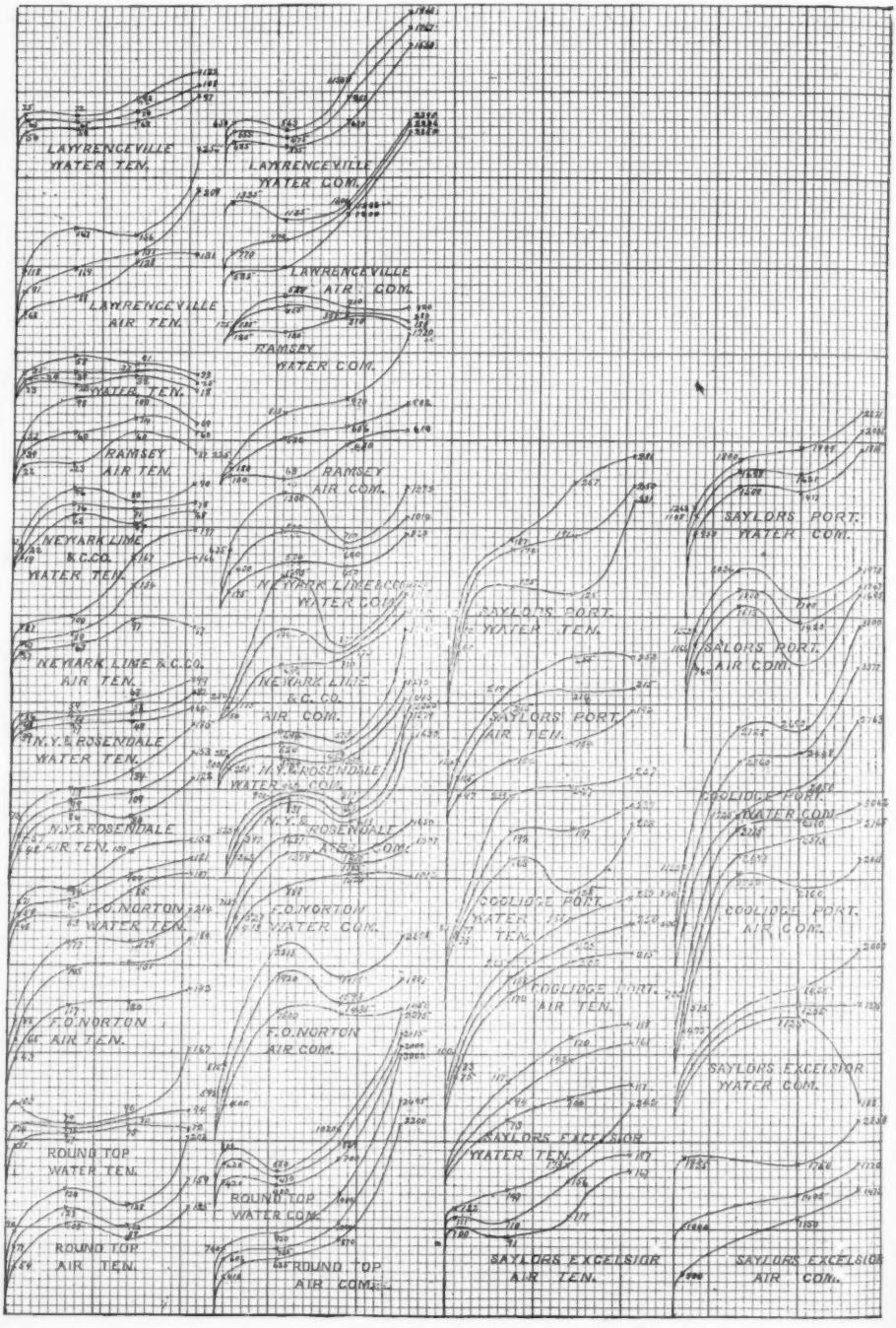
First, by immersing it in water and seeing whether the cement does not lose its form after being subjected to the water for some time and does not show any cracks or other symptons of disintegration.

Second, by allowing a blunt point to press upon the cement by means of a definite weight, the penetration being assumed as a measure of the setting properties of the cement.

At the commencement of the erection of the approaches to the East River Bridge, it was decided to employ cement for laying the masonry work. As a consequence of this, proposals for supplying cement were advertised for by the Bridge Trustees. A number of manufacturers sent samples in answer to this advertisement, and Fig. 31 gives a series of curves that are taken from the results obtained from these tests. All the samples here given were made by mixing 4 parts of cement with one part of water by weight. The mixture was then rammed into molds having a cross section of 3 inches, and a uniform length of 3 inches between the enlarged ends. After the briquettes had been in the molds for 15 minutes they were removed, half the number of briquettes being placed in water, and half being retained in the air until the time for testing. After the tension test was made, the end of the broken briquette was trued up on a grindstone and tested in compression. As a consequence, on the diagram there will be seen 4 curves for each make of cement, one curve giving the tensile strength in air, one in water, one of compressive strength in air, and one of compressive strength in water. The experiments were continued till the briquette had attained an age of one month, and tests were made at intervals of 24 hours, 7 days, 14 days, 21 days and 28 days. An inspection of these curves will reveal the fact that while they vary considerably in actual strength per square inch, all the curves bear a general resemblance to each other. Each curve rising with a slight inclination to the axis of y, until the seven day test is passed. There then occurs a point of inflection, the curve swinging towards the axis of x, in some cases even taking on a negative value, and returning towards that axis. This dropping of the curve continues until the fourteenth day is passed, when the second point of inflection occurs, the curve returns towards its former position and extends indefinitely. It would seem from these experiments that the hardening of cement is probably due to two different causes, one of which reaches the maximum about the seventh day, while the other does not come into action until after the fourteenth day. In explanation of this fact it is supposed by the author that this hardening is due to two different variations. When the cement is first mixed, the primary hardening is due to the hydration of the salts of lime and alumina by means of the water used in the mixing. This hydration reaches its maximum in intensity at about the seventh day. After that the action of the atmosphere on the cement probably causes the hydrates of calcium and alumina to give up part of the water that is absorbed, and change to silicates and carbonates. This interchange of molecules causes a slight weakening of the cement. This weakening goes on from seven to fourteen days, until after the passage of the fourteenth day the carbonates and silicates have only regained the strength of the hydrates they have replaced, and then probably go on hardening and strengthening for an indefinite period of time.

The Table 17 gives the result of a series of tests made on cement supplied by two of the most noted Rosendale Cement Company's.

These tests were made on briquettes mixed in the same manner as those in the


LAWRENCEVILLE WATER TEN.
LAWRENCEVILLE WATER COM.
LAWRENCEVILLE AIR TEN.
LAWRENCEVILLE AIR COM.
RAMSEY WATER COM.
WATER TEN.
RAMSEY AIR TEN.
RAMSEY AIR COM.
NEWARK LIME & C.C.CO. WATER TEN.
NEWARK LIME & C.C.CO. WATER COM.
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SAYLORS EXCELSIOR WATER COM.
SAYLORS EXCELSIOR AIR TEN.
SAYLORS EXCELSIOR AIR COM.

TABLE 17.

Age.	Cement A. Tension in lbs. per sq. in.		Cement B. Tension in lbs. per sq. in.	
	Air.	Water.	Air.	Water.
1 hour...	45	38	49	32
2 " ...	52	44	53	45
3 " ...	60	55	71	61
4 " ...	63	57	75	62
5 " ...	71	64	79	67
6 " ...	77	65	85	71
7 " ...	82	65	87	74
8 " ...	86	78	86	76
9 " ...	87	69	85	75
10 " ...	88	63	89	74
15 " ...	94	74	97	90
20 " ...	94	77	98	96
24 " ...	88	70	95	90
2 days...	81	72	89	86
3 " ...	91	72	91	59
4 " ...	125	69	117	68
5 " ...	155	71	115	72
6 " ...	149	83	149	83
7 " ...	103	71	111	62
14 " ...	117	94	183	86
21 " ...	148	129	149	113
1 month.	192	205	188	185
2 " .	202	199	216	220
3 " .	209	216	196	187
4 " .	201	217	140	148
5 " .	243	242	196	186
6 " .	182	180	232	212
7 " .	186	296	361	210
8 " .	319	236	311	235
9 " .	225	216	209	199
10 " .	264	226	177	209
11 " .	280	245	178	187
12 " .	255	244	190	149
13 " .	263	226	174	142
14 " .	178	249	184	191
15 " .	226	213	144	176
16 " .	248	216	292	240
17 " .			203	190

preceding tests, and treated in the same way in every respect, excepting that they were tested at intervals of from 1 hour to 17 months.

PROOF TESTS.

The testing machine is frequently employed to make proof tests upon parts of structures to ascertain whether there may be any concealed defects either in quality of materials or in character of the workmanship. For example, in making bridge columns, eye-bars, chains and cables and the like, it is customary to test each article after the manufacture is completed by placing it in a testing machine and subjecting it to a stress which is slightly in excess of that which it is calculated to meet in the structure. Nearly all eye-bars of the best bridges are tested in this way, being subjected to a strain of about 15,000 pounds to the square inch. This is largely expected to exceed the stress to which they will be subjected in the structure, but at the same time it is not intended to quite reach the elastic limit of the bar itself, and so no injury can result therefrom. Whereas, should the bar be defective in any way, either from concealed flaws, welds, or poor material, this proof stress will make the defect sufficiently obvious to cause the rejection of the piece. In many cases, however, it is doubtless that these proof tests have been too severe, for if the piece in question be overstrained so as to injure any of the fibers, or cause an incipient crystallization, the test instead of insuring safety insures the commencement of destruction.

In making proof tests the action of the piece subjected to the stress should be very carefully noted, especially to see whether there is the slightest symptom of deformation, causing, after the piece is taken from the testing machine, a permanent set in the material, signs of flaws, cracks, or other imperfections, should be carefully looked after, and any indication of weakness of any kind under proof test should be considered conclusive either for the rejection of the piece absolutely or for the continuance of further experimenting thereon.

TESTS TO DETERMINE THE VALUE OF DIFFERENT METHODS OF CONSTRUCTION.

Engineers are very rapidly ascertaining the value of the testing machine in demonstrating the best forms and the best methods to be employed in construction. To accomplish this it is of course necessary to make tests on the full-sized specimens exactly as they are to be used in the structure in question. While many experiments have been on such forms as eye-bars, columns, small plate girders and trusses, riveted joints and the like, yet the art is in its very earliest stage of infancy, so that it is almost impossible to give any rules for the guidance of experimenters in this direction, excepting the very general ones, that the pieces should be tested in a manner precisely analagous to that which they will be called upon to

resist in the structure itself, and that al circumstances during the progress of the experiment should be noted with the most minute and scrupulous attention, so that an after consideration of all of the facts thus obtained, may lead to the development of the most perfect knowledge.

The sad and disastrous failures that have occurred in various structures throughout the country during the past history of American engineering has demonstrated too completely the lack of correspondence between the physical properties of materials, as given from the data supplied by us: all test specimens and properties which have actually been developed in actual practice.

The importance, therefore, of making experiments on full-sized members is being more fully and completely realized day by day, and cannot be too strongly urged upon architects and engineers, so that it is hoped before long our country may be supplied with the requisite apparatus for testing any structures, be they small or large, in such a manner and on such a scale as to demonstrate to the world at large that America stands foremost among nations because she is foremost in her structures.

RECENT PROGRESS IN DYNAMO-ELECTRIC MACHINES.

By Professor SILVANUS P. THOMPSON, B.A., D.Sc., M.S.T.E., University College, Bristol.

From the "Journal of the Society of Arts."

II.

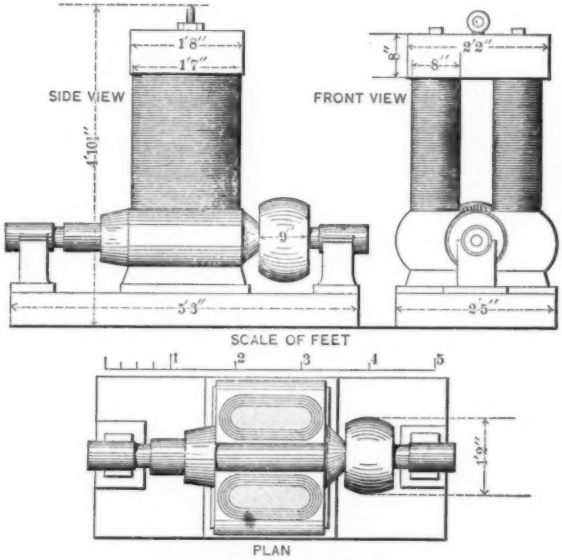
Another point in which theory has for long been ahead of practice, is in the advantage to be gained by working as nearly as possible with closed magnetic circuits; that is to say, with a nearly continuous circuit of iron to conduct the lines of magnetic force round into themselves in closed curves. The enormous importance of this was pointed out so far back as 1878 by Lord Elphinstone and Mr. C. W. Vincent, whose dynamo embodies their idea. Every electrician knows that if a current of electricity has to pass through a circuit, part of which consists of copper, and part of liquids—such as the acid in a battery, or the solution in an electrolytic cell—the resistance of the liquid is, as a rule, much more serious than the resistance of the copper. Even with dilute sulphuric acid the resistance to the flow of the current by a thin stratum is 200,000 times as great as would be offered by an equally thick stratum of copper. And in the analogous case of using a field-magnet to magnetize the iron core of an armature, the stratum of air,—or, it may be, of copper wire—in between the two pieces of iron, offers what we may term a relatively enormous resistance to the magnetic induction. If we take the magnetic permeability of iron as 1, then the permeability of air is something like $\frac{1}{20000}$, and that of copper is not very different. Or, in other words, a stratum of air or copper offers about 20,000 times as much resistance to the magnetic induction as if the space was filled with soft iron. Obviously, then, it would be a gain to diminish as much as possible the gaps between the portions of iron in the circuit. The values of the magnetic permeability for iron, air, and copper, have been known for years, yet this simple deduction from theory has been set at defiance in the vast majority of cases. We have had, a few minutes ago, an experimental proof that the Pacinotti ring, so far from having been "perfected" or "improved" by Gramme, as some very high authorities say, is vastly inferior to it. It will perhaps be intelligible now why Pacinotti's design was essentially right.

I now pass on to the progress recently made in the practical construction of dynamo-electric machines. Thanks to the kindness of several of those by whom this progress has been achieved, I am able to put before you their very latest results.

The Edison dynamo has, during the past eighteen months, received very material improvements at the hands of Dr. Hopkinson, F. R. S. Some of these im-

provements relate to the field-magnet; others to the armature. Dr. Hopkinson has, in the first place, abolished the use of the multiple field-magnets, which in the Edison "L," "K," and "E," machines were united to common pole-pieces, and instead of using two, three, or more round pillars of iron, each separately wound, he puts an equal mass of iron into one single solid piece of much greater area of cross-section and somewhat shorter length. One such iron mass, usually oval or oblong cross-section, is attached solidly to each pole-piece, and the two are united at the top by a still heavier yoke of iron. The machines have, consequently, a more squat and compact appearance than before (Fig. 17). It may be remarked, in passing, that the use of multiple pillars of iron used by Edison in the "L," "K," and "E" machines must have been prejudicial, because the currents in those portions of the coils which passed between two adjacent iron pillars must have been opposing each other's magnetizing effect. Dr. Hopkinson has also introduced the improvement of winding the magnets with a copper wire of square section, wrapped in insulated tape. This wire packs more closely round the iron cores than an ordinary round wire. In the armature the following change has been made. The iron core in the older Edison machines were made of thin iron disks, separated by paper slipped on over a sleeve of *lignum vitæ;* and held together by six longitudinal bolts passing through holes in the core-plates, and secured by nuts to end-plates. These bolts are now removed, and the plates are held together by great washers, running upon screws cut on the axle of the armature. The size of the central hole in the plates has been diminished, thus getting into the interior more iron, and providing a greater cross-section for the magnetic induction.

Fig. 17



EDISON-HOPKINSON DYNAMO.

By these improvements, a machine occupying the same ground space, and of about the same weight as one of the older "L," 150-light machines, is able to supply 250 lights, the efficiency being at the same time improved. In the new 250-light machine, the diameter of the armature is 10 inches; its resistance, cold, is 0.02 ohm; that of the magnet is 17 ohms. The characteristic curve of the machine shows that even when doing full duty, the field-magnets are far from being sat-

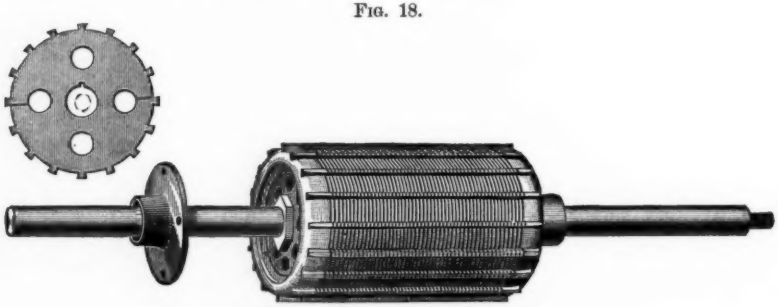
urated. It will be remarked that, in the older construction, the bolts and their attached end-plates furnish a circuit in which idle currents were constantly running wastefully round, with consequent heating and loss. An Edison 60-light "Z" machine of the older pattern, tested by the committee of the Munich Exhibition, was found to give an efficiency which, if measured by the ratio of external electric work to total electric work, exceeded 87 per cent.; but its commercial efficiency—the ratio of external electric work to the mechanical energy imparted at the belt—was only, at the most, 58.7 per cent. In a recent test made by Mr. Sprague, at Manchester, on an improved dynamo (a 200-light machine), the efficiency of electrical conversion exceeded 94 per cent., and the commercial efficiency 85 per cent.

The Edison Company states that "the weight and cost of the machines per lamp are greatly reduced," but they add a table from which it appears that the old 250-light machine cost £250, while the new 250-light machine costs £265, if made as a fast-speed machine, and £425, if constructed as a slow-speed machine.

The Siemens' machines have not been much altered during the past year; and it is a little difficult to describe the improvements which have been made, as the firm of Siemens Bros. decline, for commercial reasons, to furnish data for publication. Progress has, however, been made by this firm, especially with their compound-wound machines, of which some account has been given by Herr E. Richter, in the *Electrotechnische Zeitschrift*. It appears that three methods of combination have been tried. The shunt and series coils have been wound on different arms of the magnets; they have been wound on separate short frames, and slipped on to the cores side by side, and they have been also wound over one another. In the latest machines the series coils are wound outside the shunt windings. The regulation, judging by the curves given by Herr Richter, is not perfect. The best regulation was from a "*g* D 17" machine, of which two of the magnet limbs were wound with shunt coils of 29 layers of a 1 millimeter wire, and the other two with two layers of a 3.5 millimeter wire. The potential varied from 64 to 69 volts when the number of lamps was reduced from 20 to 9.

The Weston machine has an armature

FIG. 18.



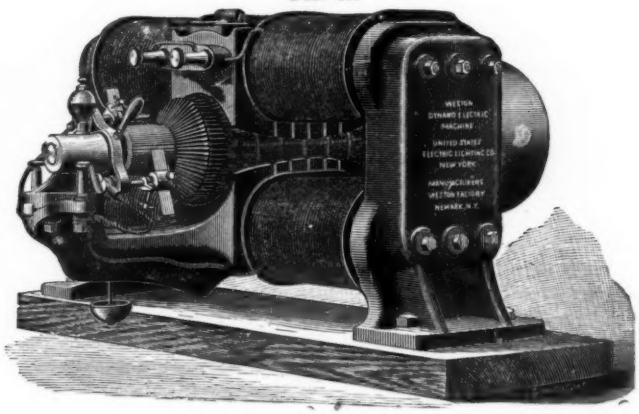
CORE OF WESTON ARMATURE.

FIG. 19.

WESTON ARMATURE.

more or less resembling those of the Siemens' machines. The core is built up of disks of iron of the form shown in Fig. 18, strung together, and presenting projecting teeth all along the surface of the cylinder. Fig. 19 shows the armature when completed. In this machine, as is also evident from Fig. 20, the pole-pieces are laminated to obviate eddy currents and heating. Recently, Mr. Weston has adopted a method of winding the armature with two circuits, so that an accident to one section shall not completely break down the machine. The latest of the Weston machines show substantial design, and many improvements in detail upon the older forms.

FIG. 20.



WESTON DYNAMO.

The machines of the Gramme type next come in for consideration. In those of the actual Gramme pattern I cannot learn that any important improvement has been made in this country; but in the States the Fuller Electrical Company, which holds the Gramme and Wood patents, has brought out several improved forms of machine, in which mechanical engineering skill of a high order is apparent. The field-magnets, frames and pole-pieces are very substantial, the ring is better built than the European types, and the collector bars are prevented from flying to pieces by the addition of an insulated ring shrunk on over their ends. In France, too, the machine has received important modifications at the hands of M. Marcel Deprez. M. Deprez's dynamo has two Gramme rings upon one axle, which lies between the poles of two opposing field-magnets, each of the two branched, or so-called horse-shoe form. These are laid horizontally, so that the north pole of one is opposite the south pole of the other, and *vice versa*, the poles being provided with curved pole-pieces between which the rings revolve. M. Deprez, who has given much attention to the question how to design a machine which, with the least expenditure of electric energy, gives the greatest actual couple at the axle, is of opinion that the horse-shoe form of electro-magnet is the most advantageous. The iron cores and yokes of the field magnets are very substantial, but the pole-pieces are not very heavy. M. Deprez's machine has a very elaborate system of sectional windings of the field magnets and a switch board, enabling him to couple up the connections in various ways. The circuits of the two rings are quite distinct, and each armature has its own collector and brushes. M. Deprez has also constructed other Gramme machines, with armatures of very fine wire, for his experiments on the electric transmission of power.

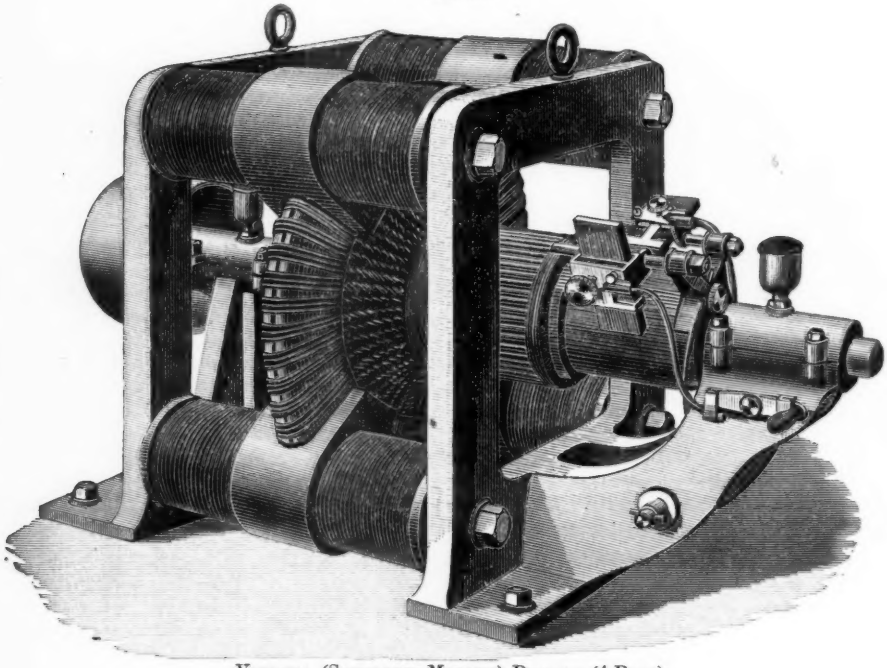
Another machine, having as an armature an elongated ring, somewhat like that of the Maxim dynamo, was shown during last autumn at the Fisheries Exhibition, under the name of the Hockhausen dynamo. The field-magnets of this machine are very strangely disposed,

the ring being placed between two straight electro-magnets placed vertically over one another, the upper magnet being held in its place by curved flanking pieces of iron, which run down the two sides of the machine, and connect the topmost point of the upper magnet with the lowest part of the lower. This arrangement, which strikes the eye as being both mechanically and magnetically bad, is claimed as one of the virtues of the machine, which, in spite of its magnets, appears to be a very good working machine. Its armature is constructed of four separate curved iron frames, upon which the previously wound coils are slipped, and which are then bolted together and secured to strong end plates. I have not seen any report on the efficiency of this machine.

We next come to the class of machines in which a flattened Gramme ring is used, and of which the machines of Fein, Schuckert and Gülcher are the best known types.

Mr. Gülcher has been steadily at work improving his dynamo in its various mechanical and electrical details. In particular, he has devoted attention to the winding of the field-magnets, so as to secure a constant potential at the terminals. After experimenting with various methods of compounding, he finds that the best results are arrived at in the following way: In his four-pole dynamo there are eight cores to be wound. Each of these receives a shunt coil of fine wire, and outside this a main coil of stout wire. The eight fine wire coils are then joined up in series with one another, and connected as a shunt to the terminals; whilst the eight main circuit coils are joined up in parallel. In proof of the degree of accuracy attained by this method Mr. Gülcher has given me many numerical data from actual tests. All of them show a very fair approximation to a constant potential, and an actually-attained constancy for a considerable range. For example, a 4-pole machine, intended to give

FIG. 21.



VICTORIA (SCHUCKERT-MORDEY) DYNAMO (4-POLE).

65 volts, gave that figure exactly, when the external current varied from 30 to 88 amperes; and gave 64 volts at 63.5 amperes, 63.5 volts at 130 amperes. With one ampere only, the potential was 61.5 volts. Mr. Gülcher adds that, in spite of all possible care in manufacture, very large machines do not give results as satisfactory as those given by machines of somewhat smaller dimensions, though the machines are of identical type, and their parts calculated from the same formulæ. He thinks this, to indicate that to obtain the same ratio of out-put and efficiency to weight, there ought to be a corresponding increase made in the electromotive force of the machine. In other words, the means taken in large machines to keep down the electromotive force to equality with that of the smaller machines are detrimental to the action of the machine.

The Anglo-American Electric Light Corporation has been manufacturing during the past year a dynamo of the flattering type, under the patents of Schuckert and Mordey, to which the not very apt name of the "Victoria" dynamo has been given. By the kindness of Mr. F. Wynne, general manager of the Corporation, and of Mr. Mordey, and Mr. P. Sellon, I have been able to learn a great deal about this machine, and to test personally its capabilities. There are two types of the new Schuckert-Mordey dynamo, one having 4, the other 8 poles arranged round the ring. As mentioned earlier in this paper, Mr. Mordey has given great attention to the form of the pole-pieces. These pole-pieces, in the earlier Schuckert machines, consisted of hollow iron shoes or cases which occupied a large angular breadth along the circumference of the ring. Similar hollow polar extensions are still used in the Gülcher machines (see Fig. 26 of my Cantor Lectures). Mr. Mordey has found my opinion, based upon the diagrams of potential at the collector, to be correct, that these wide-embracing pole-pieces were responsible for false inductions, giving rise to opposing electromotive forces and setting up secondary neutral points at the collectors. He has, therefore, by long extended experiments, arrived at a form of pole-piece which completely obviates these effects. As will be seen from Fig. 21, which represents the 4-pole Victoria dynamo, the pole-pieces, though they embrace the ring through its whole depth, from external to internal periphery, are quite narrow, and do not cover more than 30° of angular breadth of the circumference of the armature. They are of cast iron, and are cast upon the cylindrical cores of soft wrought iron which receive the coils. It may be mentioned that, in the 4-pole Gülcher machines, the wide box-like pole-pieces are also cast on wrought iron cores. The armature of the Victoria dynamo resembles in its structure the Pacinotti rather than the Gramme type. Its core is built up of rings cut from sheet charcoal iron, and Mr. Mordey has taken special pains to ensure that there are no electric circuits made in the bolting together of these cores, each plate being both electrically and magnetically insulated from the adjacent plates. Eddy currents in the core are thus almost entirely obviated. This was far from being the case with some of the earlier machines, in which, as in the Edison machine until Dr. Hopkinson improved it, the bolts holding together the cores constituted an available path for wasteful inductions. The core rings of the Victoria dynamo are toothed, as in the Pacinotti ring, and the wires are wound in the intervening gaps. There is, moreover, ample ventilation in this armature, a point not to be overlooked. Formerly, in a four-pole machine, four brushes were necessary—as in the Gülcher dynamo and the four-pole Gramme. Mr. Mordey has reduced the number to two, by the device, firstly, of connecting together those segments of the armature coils which occupy similar positions with respect to the poles; and, secondly, of connecting together, by metallic connections, those bars of the collector which are at the same potential. In the four-pole machine opposite bars are thus connected. Two brushes only are then necessary, and these are 90° apart. Fig. 22 gives the actual diagram of the potentials at the collector. There being 60 sections in the ring, there will be 15 segments of the collector from the negative brush to the positive. The potential rises steadily from the negative brush, and becomes a maximum at the positive brush, at 90°, whence it again diminishes to zero at 180°. The bars of the collector being

connected, it will be remembered, to those diametrically opposite to them, it follows that the potential will rise from 180° to 270°, precisely as it rose from 0° to 90°, and will again fall to zero in passing from 270° to 0°. If the curve from 0° to 180° were plotted again horizontally, we should clearly see how nearly regular the rise and fall is. If from this curve we were to construct another one, in which the heights of the ordinates should correspond to the tangent of the angle of slope of this potential curve—in other words, if we were to differentiate the curve—we should obtain a second curve—the curve of induction. It would show a positive maximum at about 30°, and a negative maximum at about 120°, where the slope up and slope down are steepest in the potential curve. These maxima of induction are situated very nearly opposite the edges of the pole-pieces, on the side toward which the armature is rotating. Apparently the lines of force of the field are the thickest here. In this displacement of the maximum induction we have, I think, the explanation of the inferiority of the earlier machines with broad polar expansions. In those machines the maximum position of induction was displaced to the very edge of the broad pole-piece, and, therefore, the induction was sudden and irregular. It is a singular result that while in those machines in which the ring armature is extended cylinderwise, there must be wide-embracing pole-pieces, in those in which the ring is flattened into a disk shape, the pole-pieces must on no account be wide.

The Victoria dynamo is self-regulating, having all the eight field-magnet coils doubly wound, with main circuit coils inside, and shunt coils outside. The characteristic of this machine is wonderfully straight. In a "D²" machine, wound for a potential of 60 volts, the following values were obtained. Open circuit, 58 volts; 10 amperes, 58.5 volts; 20 amperes, 59 volts; 60 amperes, 59.7 volts; 90 amperes, 59.9 volts; 120 amperes, 60 volts. It will be seen that for small loads the potential drops a little; but it is under these circumstances that the engine speed usually rises slightly in practice, so that the constancy of the potential between the mains is somewhat better than the figures would show. In actual practice, the regulation is marvelous. I have myself opened the circuit of a Victoria dynamo which at the time was feeding 101 lamps, 100 being at a distance, 1 lamp attached to the terminals of the machine. On detaching the main wire from the terminal, the 100 lamps were suddenly extinguished. The solitary

Fig. 22

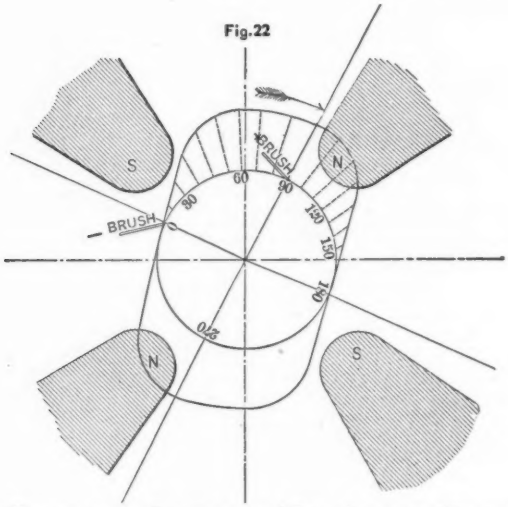
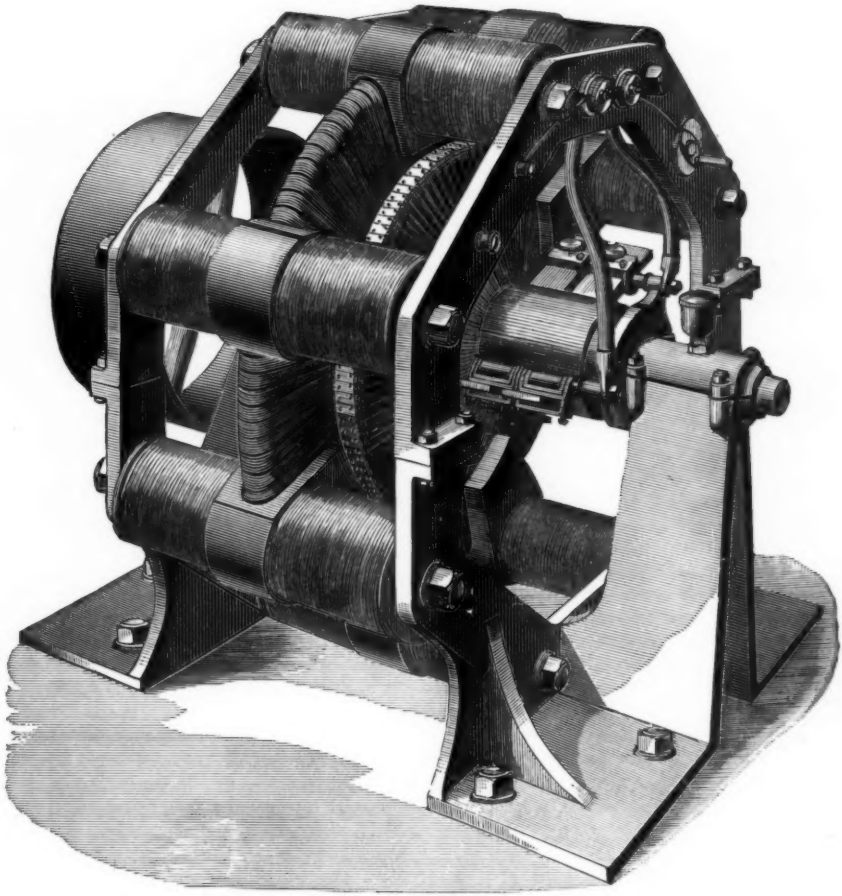


Diagram of Potentials at Collector of 4-Pole Schuckert-Mordey Dynamo.

lamp on the machine did not even wink and there was no flash at the brushes. The sparking was so slight it was impossible to tell whether the machine was an open circuit or whether it was doing full work. The lead was the same under all loads. There are not many dynamos that can show a result of this kind. According to measurements made by the Anglo-American Corporation's electricians, who have published the figures entire, the factor of conversion of this machine is 96.15 per cent., the electrical efficiency 85.68 per cent. These values assume the B. A. unit of resistance as the true ohm, and are, therefore, probably about $1\frac{1}{2}$ per cent. too high. Some of these machines are wound for low speeds for ship lighting. These machines have an electrical activity slightly higher, and an efficiency slightly lower, than the high-speed machines. They also have field-magnet cores slightly heavier, requiring, therefore, the expenditure of rather more electrical energy in maintaining the field. These remarks refer, of course, to a comparison between machines wound to light

FIG. 23.



VICTORIA (SCHUCKERT-MORDEY) DYNAMO (8-POLE).

an equal number of lamps, and to work at an equal electromotive force.

A larger type of Victoria machine, having 8 poles, alternately north and south, set around the ring, has also been constructed by the Anglo-American Corporation. This machine (Fig. 23) illuminates 750 incandescent lamps. The ring has 120 sections, there being 15 sections, therefore, between each pole and the adjacent pole of the surrounding set. As each segment of the collector is connected with those situated at 90°, 180°, and 270° distance around the set, only two brushes are required.

A rather singular commentary upon the real superiority of multipolar dynamos having rings of the flattened type over the more compact ring armatures, to which we have been accustomed in the ordinary Gramme machines, is furnished by the announcement within the past month of a new and improved dynamo designed by M. Gramme himself, in which there is a flat ring armature rotating within a crown of 12 poles. Elaborate illustrations and a detailed description of this latest of dynamos are given in the *Revue Industrielle*, of January 9th, 1884. From this article it appears that in the opinion of Mr. Gramme the new machine still requires some modifications to make it quite a practical machine. A glance at this drawing is quite sufficient to enable one to hazard a guess at the reasons. The pole-pieces are broad, nearly meeting one another. I should confidently predict from such a design the vice of sparking at the brushes and heating of the collector segments. Moreover, there are no fewer than 24 brushes! Think of the friction of 24 brushes, and the labor of making the complicated holders. It appears that in England we are at least a few steps ahead of France in the matter of designing dynamo machines.

Another 4-pole flat-ring dynamo has been designed by Herr Schuckert, of Nürnberg, and was exhibited at the late Vienna Exhibition. This machine, which had many excellent points in its design, was compound wound, and was calculated to give, at 450 revolutions, a current of 320 amperes at 100 volts.

The present drift toward multipolar dynamos of this type is very significant. There is little difference, save in detail, between the 4-pole machines of Gülcher, Schuckert, and the newer "Schuckert-Mordey" dynamo, albeit these differences are not unimportant. But all these constructors agree in adopting the flat ring. The advantage originally claimed for this construction, namely, that it allows less of the total length of wire to remain "idle" on the inner side of the ring, is rather imaginary than real, for the total resistance of the armature is but a small fraction of the whole resistance of the circuit; and it is possible to spread the field so as to make all parts of the wire active without any gain whatever, if, by this spreading there is no increase on the whole in the total number of lines of force in the field. The real reasons in favor of multipolar flat ring armatures appear to be the following: First, their excellent ventilation; second, their freedom from liability to be injured by the flying out of the coils by the tangential inertia (often miscalled centrifugal force) at high speeds; third, their low resistance, due to the fact that the separate sections are cross-connected either at the brushes or in the ring itself in parallel arc. To these may be added that, with an equal peripheral speed, the armature rotating between four poles undergoes twice as much induction as when rotating between two poles, since it cuts the lines of force twice as many times in the former case as in the latter.

I pass on to the improvements made in the dynamo by Messrs. R. E. Crompton and Co. To describe the course of development which the Bürgin dynamo has undergone in Mr. Crompton's hands would alone occupy a whole evening. The armature of the original machine, as it came from Switzerland, consisted of several rings set side by side on one spindle, these rings being made of iron wire wound upon a square frame, and carrying each four coils. In this form it is described in Professor Adams' Cantor Lectures on "Electric Lighting," in 1881. Mr. Crompton changed the square form to a hexagon having six coils upon it, and increased the number of rings to ten, so that the armature consisted of sixty segments. He then found it advisable to alternate the positions of these instead of placing them in a regular screw order on the spindle, as shown in most of the public drawings of this well-

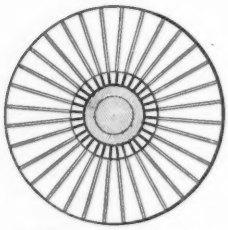
known machine. The next step was to increase the quantity of iron in the hexagonal cores, and to ascertain by experiment what was the best relative proportion of iron and copper to employ. At the same time Mr. Crompton and Mr. Kapp introduced their system of "compounding" the windings of the field-magnets. Another change in the armature followed, the rings being made much broader and fewer in number, four massive hexagonal rings, united to a 24-part collector, replacing the ten slighter rings and their 60-part collector. Quite recently Mr. Crompton and Mr. Kapp have again remodeled the style of armature and have produced a machine which, though it is not yet quite completed, shows what may be done in the way of improvement by careful attention to the best proportions of parts and quality of material. The new dynamo weighs 22 cwts. Its field-magnets are of the very softest Swedish wrought iron, compound wound. The armature is a single ring of the elongated or cylindrical pattern, and its coils are wound upon an iron core made up of toothed discs of very thin, soft iron fixed upon a central spindle, the coil being wound between the teeth as in a Pacinotti ring. In fact, the armature may be described as a kind of cross between those of Weston and Pacinotti, having also something in common in the Bergin armature, at least so I understand, for though I have, by the kindness of Mr. Crompton, been allowed to see the machine, I have had no opportunity as yet of examining the armature. Mr. Crompton's great aim has been to have as complete a magnetic circuit as possible, and that of the best quality. He has sought to increase the intensity of the field by having plenty of iron in the armature, and bringing that iron as close as possible into proximity with the pole-pieces by means of the projecting teeth. The result is an extraordinary increase in the "output," or, as Sir William Thompson puts it, "activity" (*i. e.*, amount of work done per second) of the machine. The machine is only 3 ft. 4 in. long, 12 in. high, and 2 ft. wide. The armature is 17 in. long, and 8 in. diameter. At 1,000 revolutions per minute it gives 110 amperes at 145 volts, or its "activity" is 15,050 watts; but at this speed it heats too much. The power of the field magnets is such that, at all speeds, and under all conditions of the external circuit, the intensity of the field over-masters the magnetizing action of the currents in the armature coils. There is, therefore, hardly any lead at all at the brushes, and what lead there is, is absolutely constant. There is no sparking at the brushes, and it is impossible to tell by looking at the brushes whether the current is off or on. Mr. Crompton is now constructing another machine of the same general design, but larger, to drive 1,000 Swan lamps. This machine, together with its engine, is only about 8 ft. long, 6 ft. high, 2 ft. 4 in. wide, and complete with its bed-plate, will weigh only about 8 tons.

It may be mentioned that in Messrs. Crompton's compound dynamos, as also in those of the Anglo-American Corporation, the series coils are wound direct upon the iron cores, and the shunt coils outside them, thus reversing the practice adopted by Messrs. Siemens and by Mr. Gülcher. It might have been expected that theory would have something to say in determining which practice is preferable. If the shunt coils of thin wire are outside, the prime cost for an equal magnetizing effect will probably be greater. If the series coils are outside the loss by heating in producing an equal magnetic effect will probably be increased. It might have been expected that, as with galvanometer coils, so with the coils of field-magnets it would be advantageous to get as many of the turns as close as possible to the core, and, therefore, that the thinner wire should be wound on before the thicker. But, on the other hand, it is advisable to keep down the resistance of the series coils, as they will form part of the main circuit, whilst the additional resistance, necessitated by winding in coils of larger diameter, is not altogether a disadvantage in a shunt coil. If this proves to be the right way of regarding the problem, we shall wind the shunt coils outside those that are in series with the main circuit.

Before leaving the subject of ring armatures I should like to refer to a form recently devised by Signor B. Cabella, which I think might be recommended to amateur constructors of dynamos as being easily made. The Figs. 24 and 25 show its general arrangements. The

armature resembles that of the Edison dynamo in being built up of copper strips. These are separately cut out,

Fig. 24

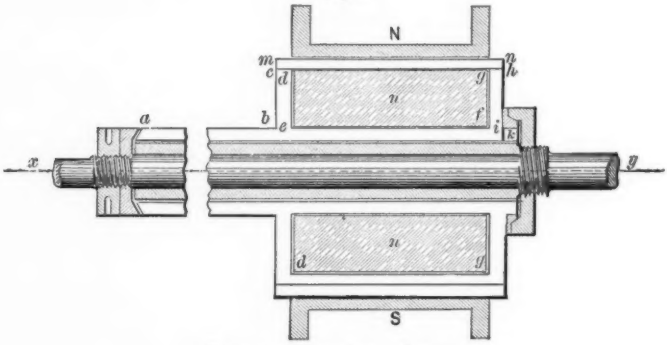


CABELLA ARMATURE.

and consist each of a straight piece having two arms, and projecting at right angles. A sleeve of insulating material is placed over the axle, and around this these copper pieces are arranged to the number of some 240 or so, having their arms projecting symmetrically around in two radial sets, one near one end and the other near the other. The channel formed thus between the two sets is lined with insulating material, and then entirely filled up with soft iron wire wound around. Then straight strips of copper, eight millimeters broad and two millimeters thick, are screwed across the outside (like the bars of the Edison armature) from the ends of one set of radial projections to the end of the others, forming the parallelogram section. But, in order to connect the ring all around in a continuous circuit, these external strips of copper are connected at their two ends to pieces which project not from the same internal copper strip but from adjacent strips. Thus an external bar will connect the anterior end of the first strip with the posterior end of the second; and so on. Every third strip is carried along the axle and connected to a segment of the collector. This construction is certainly simpler than that of the Edison armature, and might be adapted to many different types of machines. According to professor Ferrini, one of Cabella's armatures placed between the poles of a 60-light Edison ("Z," old pattern) instead of its ordinary armature, increased its power so that it could be used over 100 lamps.

Passing from ring-armatures, I come to another type of machine having disc armatures. The earliest machine of this type was due to the indefatigable Mr. Edison, who built up his disc of radial bars connected at the outer ends by concentric hoops, and at the inner by plates or washers. Each radial bar communicates with the one opposite to it; and the disc thus built up is rotated between the cheeks or pole-pieces of very powerful field-magnets, which very nearly meet, and which therefore yield an enormously powerful field. I cannot hear of any of these disc dynamos having yet come into practical use.

Fig. 25

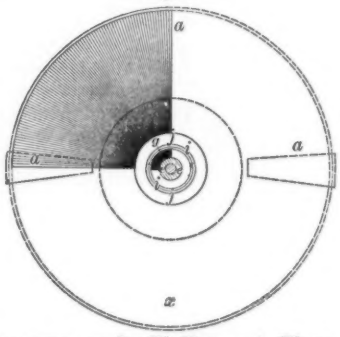


CABELLA ARMATURE. SECTION.

Another type of disc-dynamo has been invented by Sir. W. Thomson. In this case, the armature is a flat wheel, very like a flattened bicycle wheel. It is shown at *a* in Figs. 26, 27 and 28. The

radial arms or spokes of the wheel, in which the currents are induced, are all connected at their external ends to the

Fig.26



ARMATURE OF SIR W. THOMSON'S WHEEL DYNAMO.

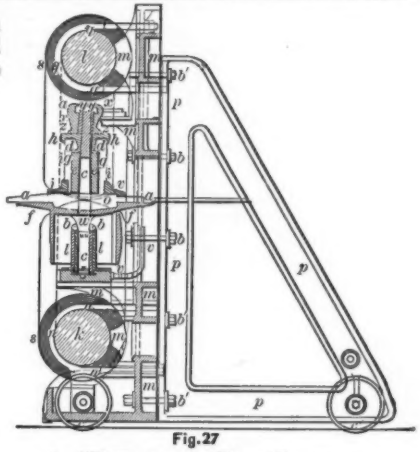
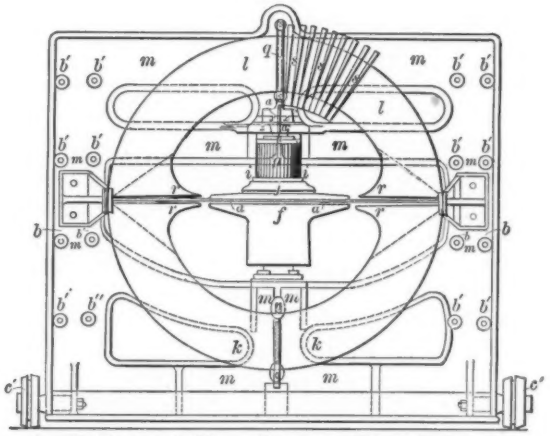


Fig.27

SIR W. THOMSON'S WHEEL DYNAMO. VERTICAL SECTION.

Fig.28

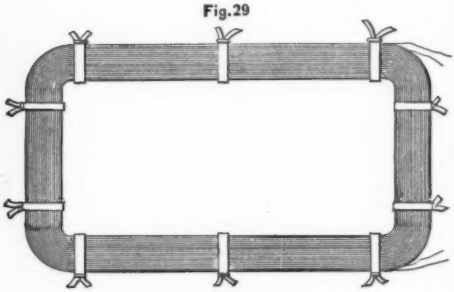


SIR W. THOMSON'S WHEEL DYNAMO. FRONT ELEVATION.

copper rim, but at their internal ends are carefully insulated and connected each to a segment of a collector or commutator, *g*. As in Edison's disc machine, so also in this, the thin disc rotates between the poles of very powerful field-magnets, which, in the case of Sir W. Thomson's machine, are semicircular in form. Sir. W. Thomson also pivots his armature with its axis vertical, and spins it like one of his gyrostats. Unfortunately, the machine has not shown itself o be in practice a success. Its construcion necessitates a very high speed, else the electromotive force would be small. If the radial bars, instead of being all joined to one rim, were united by overlapping insulated rings, each one to the one next to that diametrically opposite, and a connection brought round again at the hub to the next but one from that at which the outer rim started, then, applying similar connections all round, the radii would all be connected in circuit, and a much higher electromotive force might be obtained. I am not aware that any disc so connected has yet been tried.

Some improvements have also been made in the Elphinstone-Vincent machine. The sections of the armature of this machine are wound separately in parallelogram forms like that shown in Fig. 29, and the separate sections are then fixed upon the periphery of a papier-maché cylinder which is mounted so as to rotate between powerful field-magnets and internal field-magnets whose poles reinforce the field. In the improved machines the parallelograms of wire are so arranged that the overlapping ends lie outside the ends of the polar surfaces of the field-magnets, which, therefore, can be brought very close to the surface of the rotating cylinder. Amongst other improvements, also, segments of the collector are internally cross-connected, so that only two brushes are needed instead of six as formerly. Several improvements in mechanical details have also been made.

Fig.29



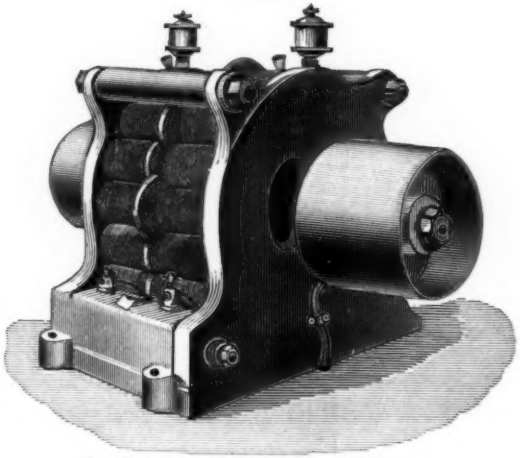
PARALLELOGRAM COIL FROM THE ELPHINSTON-VINCENT ARMATURE.

In alternate current machines something has also been done. The Ferranti-Thomson machine, which, at the date of my Cantor Lectures, had just made its appearance, has been considerably perfected. By the courtesy of Mr. Hammond, I am enabled to show Figs. 30 to 33, illustrative of the "1,000-light" dynamo, and of its working parts. Externally, the machine is scarcely charged at all; the driving pulley being a little larger in proportion. Internally, considerable changes have been made, and in these the hand of the experienced mechanical engineer is apparent. The framework of the machine is now cast in two halves, which are afterwards bolted together. Fig. 31 shows one-half of the carcase of the machine with its projecting circle of magnet cores, C, which receive the field-magnet coils. The armature, originally a single zig-zag piece of copper, has assumed the form shown in Fig. 32, in which it may be seen that the convolutions are multiplied, and are held in their places by bolts through a star-shaped piece of brass which also serves to carry to one of the two collectors the connexion with one of the zig-zag copper strip. There are in fact three complete circuits of copper strips in the armature connected in parallel arc. They begin at three of the alternate four bolts of the star shaded piece, and folding around one another, they all eventually unite with a second and inner star-shaped piece, which communicates with the second collector. Each strip makes ten turns round the zig-zags, so that there are thirty layers, all well insulated from one another by strips of vulcanized fiber. This armature is 30 in. in diameter, and a little more than $\frac{1}{2}$ in. thick in the upper convolutions, so that the opposite poles of the field-magnets can be brought very close together, and a very powerful field produced. The entire armature weighs only 96 pounds. The most extraordinary part of the machine is, however, the arrangement adopted for conveying the currents to the external circuit. The axle carries on either side of the armature an insulated collector ring of bronze, to which the afore-mentioned star-shaped pieces are respectively connected. Instead of brushes, solid pieces of metal, shown at C′ C′, Fig. 33, are employed to collect the current. These collectors hook on over the collecting rings, and bear against about 180° of the periphery of each ring. They are fixed on universal joints, and held by springs from rotating. Copper strips connect them to the terminals of the machine. The arrangements for lubricating the bearings are extremely perfect. The machine requires a speed of 1,400, and weighs $1\frac{1}{2}$ tons. Mr. Ferranti has also designed a slow-speed dynamo to run at 300 revolutions per minute, and feed 500 lamps.

A very large alternate current machine was shown at the late Electrical Exhibition at Vienna, by Messrs. Ganz, of Buda-Pesth. It was capable of furnishing light for 1,200 Swan lamps (20 candle power

each). This dynamo, which in some points resembled Gordon's well-known machine, was constructed according to the Mechwart-Zippernowsky system. The

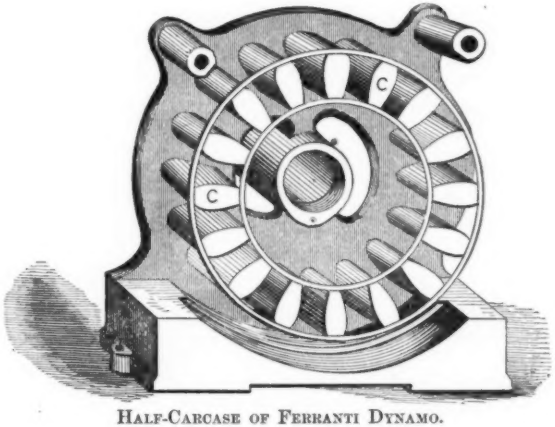
FIG. 30.



THE FERRANTI THOUSAND-LIGHT DYNAMO.

thirty-six bobbins of the field-magnet were set concentrically on an iron frame, and rotated within an outer circle of thirty-six armature bobbins. The field-magnet coils were, in fact, the fly-wheel of the high-pressure compound engine which drive the machine and its exciter. The diameter of the rotating part was $2\frac{1}{2}$ meters. A salient feature of this machine is the fact that any one of the coils, either of armature or field-magnets, can be removed from the side of the machine, in case such are needed. The whole fly-wheel can, in this way, be taken down by one man in a few minutes. An electrical efficiency of 85 per cent. is claimed for this machine.

Fig. 31

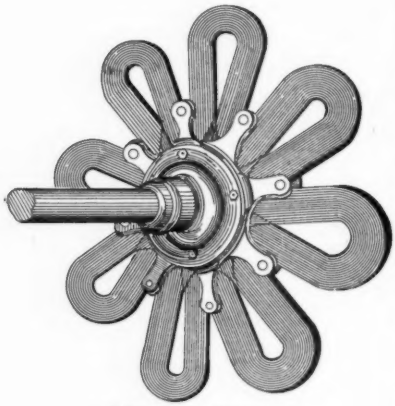


HALF-CARCASE OF FERRANTI DYNAMO.

Of one other class of machines—the

unipolar dynamo—I had intended to say something. It is a remarkable thing that, though to my knowledge a grea deal of attention has been paid lately to machines of this type, no one has yet succeeded in designing a practical unipolar dynamo. There seems to be some hiatus in the theory of this class of machines, for the very singular fact remains that those which are designed in defiance of precautions to avoid wasteful internal eddy currents will work, though badly, and those designed with such precautions will hardly work at all.

Fig. 32



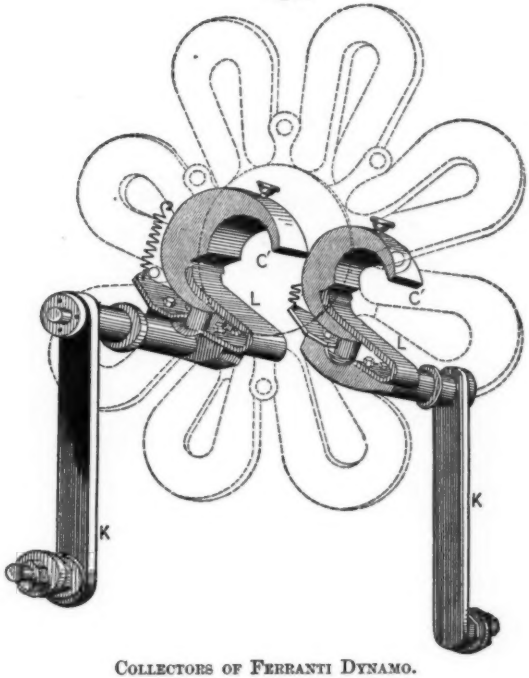
FERRANTI ARMATURE.

There are two or three other new designs for machines which, at present, can hardly be called anything but curiosities. There is, for example, a design for a dynamo (a drawing of which is given in Fig. 34), by Sir Charles Bright, in which the field-magnet coils and armature stand still, but in which the iron cores and the brushes rotate. There is another design by Professor G. Forbes, in which part of the field-magnets rotate. Mr. C. Lever has designed a machine on somewhat similar principles to the foregoing. I have myself essayed an alternate-current machine, in which both armature and field-magnets stand still, while laminated pole-pieces alone revolve. I hear also of a dynamo designed in the States in which there are no field-magnets, only two revolving armatures.

And now I have left myself no time to deal with the third branch of my subject, namely, the dynamo in its functions as a mechanical motor. In this branch also much progress has been made. If time permitted I would speak of the motors designed by Professors Ayrton and Perry, which are successful to a very remarkable degree in yielding a great mechanical power in proportion to their weight. I might have been inclined to say something of the attempts made by the same able electricians to produce a self-governing motor by various devices of centrifugal and periodic governors, and also by using an ingenious differential winding. I might tell you how I have myself worked at the question from a different point of view, and have sought to govern motors so that they shall run at a uniform speed, by devices which will not wait until the speed changes before the act, but by devices depending upon the variations in the load of the machine, in short, upon dynamometric governors instead of centrifugal ones. These things must, however, wait until some more convenient season. Time will only admit of my showing you here, in conclusion, a model designed by Mr. C. Dorman to illustrate the graphic law of efficiency of motors, which I put forward in my Cantor lectures, and which I am happy to learn has since been largely used in many different countries.

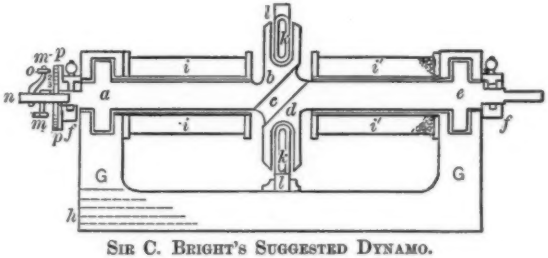
To sum up, then, it may be observed that in every department under review, the story of the past fifteen months is one of solid progress. It has been, it is true, progress of a quiet and perhaps of a commercial rather than a scientific order, yet, as I have shown you, one in which practice and theory have gone hand in hand. It is true that in some few points theory is ahead of practice, but in a still larger number practice is ahead of theory. It would be a great boon to us if our theoreticians could bring up theory to the level of practice in some of the simplest facts. We do not even know the exact law of the saturation of iron in electro-magnets, and content ourselves with formulæ, which we *know* to be incorrect. Of the laws of induction of magnetism in circuits partly consisting of iron, partly of strata of air, or of copper wire, we know very little. We want some new philosopher to do for the magnetic circuit what

Fig. 33



COLLECTORS OF FERRANTI DYNAMO.

Fig. 34



SIR C. BRIGHT'S SUGGESTED DYNAMO.

Dr. Ohm did for the voltaic circuit fifty years ago. There is ample room for progress yet in theory as well as in practice; and the perfection of theory means the deliverance of practice from arbitrary rules of thumb, and from the blunders of inexperience which have so retarded progress in the past. The history of the past fifteen months, however, gives great encouragement for the future, because it shows how much may be done, even in the face of great commercial depression, by those whose knowledge and experience give them a deliberate faith in the future, and whose efforts are directed toward no uncertain end. A steady development toward the yet far distant goal of perfection is going on unceasingly. The progress of which I am permitted to be the chronicler to-night is progress of the good and substantial kind, that owes nothing to the excited rush of Stock Exchange speculations, and which, not having been nurtured at an unhealthy

fever heat, is destined to be of permanent value.

DISCUSSION.

The Chairman said they were much indebted to Professor Thompson for the extremely clear and able manner in which he had brought forward the progress of dynamo-electric history, and he was very much pleased to find that in that progress he had given the first place to practice, and the second place to theory. He had always found theoretical men rather inclined to look with a certain amount of disdain upon practical men, and to think that practical men knew nothing about their subject unless they followed the dictates of theorists. But a change seemed to be coming over the spirit of the dreams of philosophers, and they were now paying much more attention to the teachings of experience than they used to. Professor Thompson had shown how, during the past 15 months' progress, the lead had been taken by practical men; and he had been rather amused at this, because not much more than a week ago he heard him make similar remarks upon a paper brought before the Royal Society by Professor Hughes, one of the most wonderful experimenters and discoverers of the present day. Professor Hughes succeeded, with pins, bodkins, bonnet wire, match boxes, tin kettles, and similar pieces of apparatus, in extracting from nature some wonderful secrets, and he had brought out some very beautiful instruments, which had been the result of incessant toil and constant experiment in every shape and form. Professor Thompson, at the Royal Society, gave the theory after Professor Hughes had shown his instruments, and at the end of the paper expressed surprise that Professor Hughes' instrument accorded with his theory. This was much what he had told them now, though not quite in the same words, that, after all, experience was the only safe guide in teaching one how to make instruments for real practical work; and theory was a very good servant indeed when it came afterwards, and gave a plain, simple, unvarnished tale, which all could understand, to enable them to understand the peculiar action which had taken place. Professor Thompson had alluded to the theory of the dynamo machine, and divided his theories into three—the physical, the algebraical, and the geometrical; and he was bound to say that his own diagramatical representation of the action of dynamo machines, and of the performance of magnetic fields, were perhaps the most interesting part of his paper. The way in which he had worked out the magnetic field had taught everybody more about this subject than they knew before. But he must say that he objected *in toto* to this application of the term theory to explanations which Professor Thompson had given of the action of the dynamo machines. Theory was neither algebraical, nor geometrical. What Professor Thompson called theory was an explanation—a mode of representing what took place. But a theory was more than that; it was an explanation—a mental picture—of what took place in nature which placed it beyond mere hypothesis. For instance, the theory of light was an explanation of a certain physical action which took place in the universe, which enabled the vibrations of the sun to be represented in our eyes. The theory of heat was something which enabled us to conceive of matter itself vibrating and the space around it also vibrating in unison; but he objected to applying the term theory to either an algebraical or geometrical description of the actions of the dynamo or any other machine. He, and all other electricians, wanted to have some idea conveyed to their minds of what took place in a wire, in iron, and in the space occupied by the iron and the wire, which produced those marvelous results which they saw in the electric light and in the transmission of force, and to this sense he would confine the word theory.

Mr. Liggins said he was not qualified to speak on the scientific aspect of the question, but he was much interested in hearing of the progress which had been made during the last sixteen months. He was glad to find that some of the bubble companies were going to the wall, and when some of the systems which had very little merit were out of the way, there would be a chance for some simple and practical method to come into use. One day last week, at the Edgwareroad Station, he noticed that the electric arc light was wonderfully steady, and the superintendent informed him that an improvement had just been introduced, which reduced the cost from £200 to £8.

That was all he heard about it, for he had not time to inquire further particulars, but he hoped the time was not far distant when the public would derive a benefit from some of these improvements.

Mr. Percy Sellon then gave some particulars of the Victoria machine. He said that taking an original Schuckert machine, capable of giving 60 incandescence lamps of a certain power, by substituting four poles for two, the mass of which, both in iron and copper, was very little in excess of that in the original two, and using identically the same ring, they obtained 100 lights and a much better result in the commutator. From the old Schuckert machine they got a very similar diagram to that which had been shown, among these integrated from Isenbeck's as a bad one with false inductions (Fig. 6), the output of the machine being crowded into two bobbins, and on the other side there was a back electromotive force which caused considerable sparking. This was almost entirely removed by the use of four poles, and at the same time the internal resistance was brought down to about one-fourth what it was before. In constructing large dynamos for 500 lights and upwards, they were increasing the number of poles to 6 and 8, and eventually, probably, they would go to twelve for very large machines. The great advantage of this was that when you brought the poles together you had a given number of lines of force crowded into a very much smaller space; the distances of the centers between north and south polarity were much less, and whilst the number of poles increased, the intensity of the field remained the same, and, therefore, a given length of wire and iron, revolving at a certain speed, would give a decidedly higher result. With regard to the system of compound winding, he should say that a great deal of the credit was due to an *employé* of the firm, Mr. C. Watson; and it was applied without any formula or mathematics, and the very first machine constructed without any experiments gave as good a curve as the one shown on the diagram. It gave a difference of potential of only about 3 per cent. when the whole number of lamps was at work, and when the armature was simply working on the shunt. That showed theory was not always necessary.

Professor Thompson, in reply, said he did not agree with the Chairman's criticism on his use of the word theory. He thought that he had indicated that these three methods were really three aspects of the theory. The number of lines of force which he had been dealing with might be expressed by certain length of line, geometrically, or by the symbol n alphabetically, or when viewed optically, by a mere pictorial demonstration. What some people wrote n for, other people indicated by drawing a line in a certain direction. It was only another way of arguing about the things themselves. He wanted them not to ignore those essential considerations which constituted the true theory, and which underlay the mere facts of observation. They were approximating to that theory by one process or another, sometimes by algebra, sometimes by geometry, sometimes by diagrams, and it made all the difference between working intelligently and unintelligently to have a principle to guide one. He had been trying to discover, both from *a priori* considerations, and from the teachings of experience, what the principles were which ought to guide practice; and he thought he might claim to have vindicated the claims of theory. It was quite true that theoretical men had been sometimes loth to allow any consideration to practical men; but, on the other hand, practical men would often refuse to have anything to do with theory. The vindication he wanted to put forward was this: in his Cantor lectures, and since, he had been working diligently at the curves of potential around the commutator, and to-night he had connected them with the curves of Isenbeck. Part of the improvement he had noticed in the Schückert machine was directly due to the advice he had given Mr. Mordey, and to the world at large, on shaping of the pole-pieces to that form which would give the best result on the commutator in respect to the rise of the curve of potentials. Originally the Schückert machine had great shoes of iron as pole-pieces around it, now they were narrowed and tapered. It was found that where you had pole-pieces on the two sides of an ordinary cylindrical Gramme ring, it was better to have them curved around through a large arc, because it gave a flatter field, and the cutting of the

lines of force was more regular. Now they were finding that practice was leading in an exactly opposite directions for flat-ring machines with the poles at the sides; the shoes were being cut down into little narrow pole-pieces. Theory had led practice to that, and theory, too, had pointed out the relation between the curve of the potential and the induction due to the pole-pieces. After theory had indicated the source of error and a possible means of remedy, they had gone on experimentally cutting down the pole-pieces until they got the proper curve on the commutator. He might further claim, as a vindication of theory, that M. Gramme, who had had fourteen years' experience in constructing Gramme machines, and to whom they owed an enormous debt of gratitude, had not yet arrived at the real point which had been reached in England. M. Gramme confessed that this 12-pole machine of his was not yet perfect, and he (Professor Thompson) had little doubt that the reason was that he had great flat pole-pieces nearly meeting each other. He would stake his opinion on the fact that if he had only made the poles narrower he would have had a better curve of potential, a machine that did not spark so much. That was the deduction he should draw at once from the potential curve. He claimed that it was entirely admissable to call a generalization from which deductions of that kind might be drawn, theory; it was theory in the truest sense of the term, because it pointed the way for practice to follow. He did not require to know what electricity was, or what magnetism was in a piece of iron, or what was the ultimate form of the transfer of force across the space between them, before he used the word theory. He regretted that cold water should have been thrown on his attempt to raise the construction and design of dynamo machines above mere rules of thumb, which were the essence of practice when unenlightened by theory. Practice without theory went on blundering in the dark, and though it was possible to blunder into success, it was much more easy to blunder into failure. With regard to the invention which had been mentioned which would reduce the cost from £200 to £8, he need hardly say he should be much interested in further details; he believed it was the first instance on record in which an inventor dared to claim to have reduced the cost more than 50 per cent., that being the usual reduction claimed in the stock phrase of company promoters.

The Chairman, in proposing a vote of thanks to Professor Thompson, said he did not apply the word "theory" in the sense he objected to. He thought that certain geometrical and algebraical investigations were essential in carrying out any practical question, but he objected to the use of the word "theory" to explain what was really better expressed by the word "principle." Prof. Thompson himself used the word "principle," and had detailed the principles that governed the action of the dynamo machines, and it had been in following these principles that such vast improvements had been made. He should like to have heard some description from Professor Thompson of a class of dynamo machine which was now coming into use daily very largely for the production of copper by the deposit of the metal from its salts. This was being done both at Swansea and at Birmingham. Mr. William Elmore, a hard worker in this field, who had works at Blackfriars, was setting up very large works at Swansea for the extraction of copper from impure ores by this method, and when next Professor Thompson brought the subject before this Society, as he was sure the council would insist upon his doing next year, he hoped that he would pay a little attention to those dynamo machines that were met with in other fields besides the production of electric light and the transmission of power. Again, he was rather disappointed to hear him pass by very lightly the performance of the Hockhausen machine, which was certainly the most distinguished feature of the Fisheries Exhibition. He did not think that that machine had received the attention it deserved, or been studied so carefully by Professor Thompson as others. Its performance was simply wonderful, and though he had not yet seen the Victoria machine, his own impression was that of all those he had seen the Hockhousen was decidedly the best. Perhaps Mr. Crompton's was an exception, for he had this advantage over Prof. Thompson that he had seen the performance of the Cromp-

ton machine. It was certainly a wonderful little thing. You saw before you apparently a lump of iron which was motionless and silent; it appeared motionless because it went so quickly, and it was silent because it was so beautifully made, but with that machine currents of electricity were produced that had increased the output of the form known as the Crompton-Burgin machine exactly 100 per cent. The great lesson to be learnt was this: advance was being constantly made in all these machines, an advance whose future they could scarcely see an end to, and every day they could perceive how, by the combination of theory and practice, they were developing the power of producing electricity to an extent which no one had dreamed of. What with the improvements such as had been mentioned that evening, with improvements in electric lamps and various other appliances, he did not think there was any chance of that end being reached which gas shareholders were so anxious to see.

INTERNAL CORROSION AND SCALE IN STEAM-BOILERS.

By G. SWINBURN KING.

From the "Journal of the Society of Arts."

In presuming to offer any remarks on corrosion and scale in steam boilers, I have no thought of instructing eminent engineers and chemists in a matter concerning which it would better become me to listen to instruction from them. But, profiting from that which they have already taught me, my desire is to call renewed attention to an important subject, and to endeavor, in popular language, to interest the philanthropist and the economist, to whom it especially appeals, and to lay before the owners of steam power, and their superintendent engineers, the results of my researches; pointing out what I believe to be the surest methods of overcoming evils which are known to cause a considerable loss of life and an enormous annual waste of property.

Further discussion and inquiry may result in the discovery of better methods, but, in the meantime, those that have proved effectual cannot be too widely made known.

A former connection with the Admiralty led me to reflect on the importance of this question and to take a great interest in it. Since that period I have made personal investigation into the subject in the great shipping ports of London, Liverpool, Cardiff, Hull, and other places; and in the manufacturing centers, such as Warrington and the neighboring towns.

From an economic point of view, the subject affects the widest interests in this country, the birth place and home of steam power. Besides its relation to the navy and the shipping world generally, it is of vital importance to every owner of factory, mill, or mine; and, as it must ultimately affect the cheapness of production, it should concern every class and every consumer.

Since the days of James Watt, now a century ago, when the giant steam was finally subjugated to the will of man, there has been a constant cry for more power.

In the earliest days of steam as a motive power, boilers were sometimes made of wood, and afterwards of stone; and these primitive materials were followed by the adoption of cast iron, generally in a spherical or hemispherical form, as being best calculated to hold in bonds the expansive force. Copper was found to be inferior in tensile strength, and too expensive for the purpose. Cast iron has now been discarded for wrought iron and steel, and the spherical form of boiler has given way to the tubular or cylindrical, with tubular furnaces and flues running through and within it. The Cornish, the Lancashire, the Galloway, and marine boilers are all constructed after this fashion; and the greatest efforts of our ablest engineers have been directed, not in vain, to construct a boiler strong to

resist, strong to drive, and strong to meet the cry for more power.

But, from the moment one of these structures is mounted into its position, insidious foes are working, which, sooner or later, will compass its destruction; and among the foremost of these must be placed corrosion and incrustation, or scale. These, while constantly reducing the strength of the boiler, appear to be the most common cause of explosion.

The Boiler Explosions Act came into force on the 12th July, 1882, and from that time to November 1883, fifty-seven explosions had been reported to the Board of Trade. This Act, however, has only a limited scope, and does not apply to steamships having certificates from the Board of Trade, nor to H. M. ships, &c., nor to boiler explosions on railways, nor to those investigated under the Mines Regulation Act of 1872. The total number of deaths resulting from these particular catastrophes was thirty-nine, and in addition, forty-six persons were injured. Such fatal explosions—happily rare—as that on board the Royal mail steamer Severn, last November, by which nine persons lost their lives, are excluded from this return.

Mr. Gray, in his report to the President on the explosions occurring in the twelve months ending July, 1883, states that,

"The prevailing cause of explosion is the unsafe condition of the boilers through age, corrosion, wasting, &c.; and [he adds] a noticeable feature in many cases is the absence of any effort on the part of the steam user to ascertain the condition of the boiler, and, consequently, of any attempt to repair defective plates or fittings."

The report of the Registrar-General for 1881, for England and Wales alone, shows that the total number of deaths in that year, directly attributed to boiler explosions, was 51; but, besides these, no fewer than 652 persons were killed by scalding in various and unstated ways; and though it cannot be stated as a fact, it is fair to assume that at least a proportion of these deaths by scalding, from ungiven causes, arose from boiler explosions. These, it must be remembered, are the bare official returns of the killed. Add to them only an equal number of wounded, and it needs no vivid imagination—no affectation of word-painting on my part, to picture to your minds the greater suffering, unrecorded, of mutilated men and women, of bereaved families, and homes made desolate.

If some of these terrible disasters can be traced to their cause, and a remedy found—if life can be saved—as I am fully convinced it can be, this paper will not have been read in vain. Such is the humanitarian side of the question; but the loss of property, arising from decay, is not indicated by the number of explosions, and is far in excess of that which is thus suddenly occasioned. Every steam user knows the heavy annual outlay necessitated by rapid deterioration of boiler plates and tubes, the amount of fuel wasted by reason of scale encrusting the interior, the injury it inflicts on the boiler, and the labor and expense of chipping it out with the scaling hammer.

Mr. Robert Wilson, in his valuable "Treatise on Steam Boilers," says:

"As a rule, steam boilers explode from one cause alone—over pressure of steam." "It often happens," he says, "that boilers are too weak for the pressure they are worked at, and no accumulation of pressure beyond this is requisite to bring about their destruction."

A boiler may be unfit to bear its working pressure from four causes, which he enumerates: (1.) Its original design and strength not being understood by those who fix the pressure; (2), the strength although originally sufficient, having been gradually reduced by wear and tear; (3), by a sudden overtaxing as by unequal contraction; (4), by bad workmanship or material.

I propose to confine my remarks to the second of these causes, and to inquire whether the aggregate of casualties which are attributable to wear and tear cannot be reduced, and whether a remedy cannot be found for the weakening of the various parts of the boiler by corrosion and "pitting," and by the over heating of furnace plates and tubes, consequent upon the formation of lime scale upon them.

Internal corrosion is a trouble from which few boilers entirely escape; but marine boilers are the greater sufferers. Land boilers are subject also to very serious and often rapid decay from external corrosion, but I do not propose to make

more than a passing remark on external decay. The principal causes arise from undue exposure to the weather, unscientific mounting on possibly damp brickwork, leakage consequent upon faults of construction, or negligent management on the part of the engineer in charge. These sources of corrosion are commonly known, and the measures necessary to prevent them are now well understood; although it must be admitted they have been often culpably neglected.

Internal corrosion may be divided into ordinary corroding (or rusting) and pitting.

Ordinary corrosion is sometimes uniform through a large part of the boiler, but it is often found in isolated patches, which have been difficult to account for.

Pitting, which is still more capricious in the location of its attack, may be described as a series of small holes often running into each other, in lines and patches, eaten into the surface of the iron to a depth sometimes reaching a $\frac{1}{4}$ of an inch. Pitting is the more dangerous form of corrosion, and the peril is increased when its ravages are hidden beneath a coating of scale or fur which may have gathered over it. For without great watchfulness this insidious canker may go on unsuspected until a catastrophe reveals it.

Ordinary corrosion has been commonly accounted for by the presence of acids in the water, but the mysterious ways of pitting have been an enigma to engineers; and although a variety of theories have been advanced to explain its capricious and peculiar methods, none were conclusive until recent scientific investigation discovered the true agency.

It was long suspected that galvanic action, or electricity in some form, had to do with both corrosion and pitting. One theory was that voltaic action was set up between the iron shell and brass tubes, and another that differences in the quality of the iron plates produced the same result. Experiments were made, from time to time, to test these hypotheses, but they seem to have ended, for the most part, in the conclusion that electricity was inoperative either as a cause or a cure. Considered as a cure, it was set aside by some eminent engineers as mere empiricism; but most thoughtful men admitted that the action of electricity, if it really existed, was not understood. New light has since been thrown upon the subject, and altered views now prevail; but I will not anticipate.

There is another form of decay in boilers, known as grooving. This also comes under the head of wear and tear. It may be popularly described as a kind of surface cracking of the iron, caused by its expansion and contraction under the influence of differing temperatures. It is attributable generally to the too great rigidity of the part of the boiler affected, and it may be looked upon as resulting from faults of construction. It is, therefore, outside the scope of this paper, except in so far as it may be, and frequently is, aggravated by internal corrosion, which fastens upon the cracks and eats them more deeply into the iron.

The hard calcareous scale which is deposited by the water on the internal surfaces of the boiler may be taken roughly as identical with the fur which forms on the inside of a tea-kettle. It is composed chiefly of salts of lime, and is known by many names in different districts. I have collected a few specimens for inspection, recently taken from both land and marine boilers, which will give a more definite idea to what it really is. (Specimens produced.) On the whole, it is perhaps a greater enemy than internal corrosion, especially in land boilers, as it brings in its train so many destructive agencies, and involves so many expenses. As of fire it may be said that it is a good servant but a bad master—for a thin covering of about the substance of a coat of paint is found to protect the iron from rust, and is therefore favored by all engineers.

Beyond this point, however, it is an unmitigated evil. In the first place, it necessitates a great waste of fuel, varying according to the thickness and character of the incrustation; but the waste of coal may be fairly put down at an average proportion of not less than 100 per cent. The reason is this, that scale is a very efficient non-conductor of heat, and when it is interposed between the furnace and the water the latter is unable to take up the heat, which, by consequence, goes away unused up the flues. Then again the iron, or other metal, of

the furnace and tubes, being no longer protected by contact with the water, becomes red hot, and is burnt and twisted, to the imminent danger of the boiler, while a heavy expense is incurred for renewing the plates and tubes so affected.

When the scale is thick and hard, the proper examination of the parts beneath it is impossible until it has been entirely removed. Indeed, if it were not removed, the boiler would become unworkable. Scale, therefore, being so great a foe, has to be periodically chipped with hammer and chisel; and the process of chipping is so severe that it tends very greatly to wear out the boiler. The cost of chipping is in itself a heavy item; and it should be borne in mind that a factory boiler must, during the process, perhaps every six or eight weeks, be put out of work for several days at a time.

Scale will stop the feed pipe, which supplies water to the boiler; or hardening over the fusible plug in the furnace crown, which is intended to melt and give warning when the water is dangerously low, will nullify this precaution; and it has thus caused both collapse and explosion.

To dwell on the nature and detail of all the various deposits that afflict steam boilers would occupy too much time, and it is not necessary for my purpose; but, concerning carbonate of lime, which is often a source of danger, I must offer here a few remarks.

This is deposited as a pulverent body; and under certain conditions, chiefly of neglect on the part of the engineer in charge, will form a hard scale similar to that we have been considering, but by proper attention a great deal of it may be got rid of by blowing down, or emptying the boiler to the extent of a few inches day by day, by the scum cock, while it floats near the surface, or by the blow-off cock when it has settled at the bottom. If, however, this floury deposit is allowed to accumulate, and thicken the water, it will produce priming, which may be described as "boiling over," the same process which is apt to take place in boiling a saucepan of milk, or of water thickened with flour. The water is driven with the steam into the machinery, and may knock off the cover of a cylinder, or blow out the bottom of it. The second great danger which it involves is, that lying in a mass upon the furnace plates, it may prevent the steam from rising, and thus the water being lifted on the top of the deposit by the steam held beneath it, the furnace is left without protection, and is liable to be over-heated, and to collapse by the pressure of the steam.

However, these particular dangers may be averted, as already indicated, by due care, without which no scientific appliance is of any avail; and touching this point, I may quote Mr. Michael Reynolds, the author of several excellent engineering works. After inculcating care in various ways, he says, in his practical and significant style: "Any boiler can be made sensitive and hard to manage. Fire it on no system, feed it with water just as the lead plug is in danger, and fill it to the whistle; and your boiler will one day give a big kick." Many a big kick, it may be added, has been occasioned by want of ordinary attention to well-known rules.

The difficult problems that corrosion and scale have presented to engineers and chemists are evinced in the number of patents that have been taken out for chemical compounds to solve them. Hundreds of these compositions have been put into the market, and the number is still increasing; a proof, perhaps, that no panacea has been discovered; although many preparations are still in use by different engineers. These compounds have in truth become so numerous, that every new one is looked upon as another nostrum, and perhaps by the majority of interested persons it is not credited even with the virtues it may really possess.

The chemical laboratory has been ransacked in vain for an absorbent of oxygen that will stop corrosion, or an alkali that can be applied without the risk of causing priming.

With regard to the inutility of boiler compositions, I cannot do better than quote Mr. Hannay of Glasgow, of whose invention I shall have to speak later on:

"Boiler composition [he says] can be classified under two distant heads. First, there are compounds of the nature of precipitants, which are intended to render the incrusting material pulverent instead of coherent. But these do not at all prevent corrosion, and the best compounds only partially prevent incrusta-

tion. The second class, called solvents, are chiefly ammonia salts, which form soluble double salts with lime, and so prevent incrustation. They are, however, very dangerous, as they dissociate under high-pressure steam, and act rapidly on iron, thus increasing the corrosion. Besides, in marine boilers, under great pressure, the presence of even a minute quantity of ammonia salt causes violent 'priming,' that is, sudden ebullition, driving the water of the boiler over into the cylinders of the engine, and sometimes causing the fracture of the cylinder or piston rod. Experiments were made with nearly every possible form of chemical boiler composition, and they were all found wanting."

If further condemnation is required, it will be found in a report of Mr. Lavington Fletcher, of the Manchester Steam Users Association, an engineer of acknowledged and leading authority in such matters. He is reported as saying:

"The number of anti-incrustation compositions was very numerous. Their component parts were veiled in mystery. Many of them proved injurious to the boilers on actual trial. Some lined the plates with a glutinous coating which, while it had the desired effect of keeping off the scale, unfortunately at the same time kept off the water, in consequence of which the furnace crowns became over-heated, strained, and bulged out of shape. The members, therefore, were warned not to adopt any of these boiler compositions without the greatest caution. As the incrustation compositions were costly, blowing out was too often given up when they were used. The practice of neglecting blowing out was strongly objected to, and an explosion that occurred at Bury from that cause was referred to as an illustration."

Mr. J. A. Rowe, an able engineer and officer of the Board of Trade, observes with regard to compositions, that some of them may be useful to prevent the formation of hard deposit, but the "objection to the very best of them is that their acids tend to injure the boiler. . . The majority of them have passed into oblivion, and those that survive seem doomed."

The superintendent engineer of a Bristol company told me of an instance in which, after careful trial, he had adopted a compound which was strongly recommended. It was used in the boiler of a ship on a voyage to America, and it answered its purpose admirably; but, on the return voyage, the engineer in charge put too much of the fluid into the boiler, and the feed-pipe was consequently stopped. The openings into the water gauges being also stopped, they continued to indicate a sufficiency of water until it had fallen to the level of the furnace crowns. The consequence was, the furnaces burned and collapsed, and the ship was seriously disabled on the high seas.

Some compounds cure one part of the evil, and do not touch others, while some again are extremely dangerous to use in a boiler under steam pressure.

Among the many inquiries directed upon the general subject, some of the most exhaustive and minute have been those instituted by the Admiralty, extending from 1874 to 1880. They were carried out by committees appointed to inquire into the causes of decay in the boilers of H. M. ships. The committees were invested with very abundant powers, and were directed to propose measures tending to increase the durability of boilers.

The results of their labors are contained in very able reports, full of valuable information and practical suggestion; but for the purpose of the present inquiry, they may be briefly summarized as follows:

1. With regard to a prevailing belief that the presence of particles of copper in a boiler was a source of injury, they state, first, that the quantity carried into the boiler is extremely small; and, second, that no injurious effect of importance can be produced by it.

2. That fatty acids resulting from the use of vegetable and animal oils for lubrication were a source of injury, and they recommend the use of mineral oils.

3. Moist air, or water containing air, are powerful corrosive agents. They recommend increased density in the water, especially in boilers fed from surface condensers, and that the boiler should be emptied as seldom as possible.

The main conclusion, however, at which the committee arrived—the great prin-

ciple that they asserted and demonstrated —was that galvanic action, induced by the contact of zinc with the iron of the boiler, was the best and only trustworthy remedy for corrosion; and that, so long as the metallic contact was maintained, little or no corrosion would go on.

They adopted a plan of hanging slabs or plates of zinc by iron straps from the stays or rods within the boiler, the zinc being held in a clip in which it was tightly bolted. The theory was perfect, but the weak point in practice was found to be in keeping up electric contact between the two metals. The zinc and the iron not being metallically connected, but only mechanically pressed together, were liable to be so far separated—by the corroding of the surface of the zinc—that the galvanic current was soon weakened and destroyed.

The committee endeavored to circumvent this difficulty, first, by fixing in each boiler an excessive number of plates, so that (apparently) if electric contact should cease even in many plates, it might chance to be maintained in some; and, secondly, they directed a frequent examination with a view of renewing the contact, and putting in fresh plates in lieu of those destroyed by corrosion.

This system was the best they were able to arrive at, but it could be maintained only at such a cost that, to use the words of the report: "The expense of the zinc necessary for efficient protection is undoubtedly an important element in determining how far it should be adopted." For besides the expense of fitting, examining, and renewing the excessive number of plates already referred to, the committee go on to say that "the actual waste of zinc is much greater than that due to the protection of the boiler; and it becomes important to ascertain whether that waste cannot be avoided."

With great care, however, this system was found to prevail against the inroads of corrosion; and herein was a distinct advance, although it still left the question of incrustation by lime-scale comparatively untouched. Indeed, it is stated that the scale which formed in some of the boilers in which slabs or plates were used became "harder and more adherent," and it was therefore suggested that the zinc should be periodically removed altogether, for a limited time, in order that a slight corrosion forming under the scale might enable it to be separated more readily from the iron.

Under the Admiralty system, then, it must be presumed that the bad effects arising from scale, such as the burning of the iron, the waste of coal, and the injury caused by severe chipping, are still a source of trouble and expense; and such I believe is the case. I have before me a specimen of the scale which formed in two months in one of H. M. steam vessels. It was recently taken from a boiler treated on the Admiralty method, and considered to be in very good order.

The committee's report attributed this hard scale to the action of the excessive quantity of zinc which was found necessary for protection when used in the form of slabs or plates. This, however, is now shown to have been an erroneous conclusion, the real cause being that the galvanic current set up under the Admiralty system has not sufficient intensity. I hope to explain this point a little more fully later on.

Now, having pointed out where the Admiralty method fails, I must give credit to the inventor, *per contra*, for the large amount of success it has, nevertheless, achieved. Experience teaches us that few inventions cannot be improved upon, and Mr. Weston himself, of whom I am about to speak, would be the last to claim perfection for his particular plan of protecting boilers by means of zinc.

Mr. William Weston is the Admiralty chemist at Portsmouth, and was a member of the Boiler Committee, whose collective labors are worthy of all praise. It is due to him, however, to state that the system of protection finally adopted in the British navy was initiated and worked out by him, with indefatigable pains and assiduity; and that his method, whatever may be its shortcomings when viewed in the light of later discovery, has worked so well that near half-a-million of money must have been saved to the navy and the British taxpayer since its introduction.

Before the application of the galvanic principle, it was not an uncommon occurrence for the boilers of H. M. ships to be worn out in one commission, or, at least, to become so unsafe to render their renewal necessary; and, as a case in

point, I may mention the *Bellerophon*, whose boilers had to be renewed, after serving only one commission of three or four years, at a cost of some £30,000.

A man who serves the Queen is content to do his duty, and must often do so without being singled out for praise or reward even for special services; but in this paper I am at liberty to mention the name of Mr. Weston with honor, and to claim for him the personal credit which is his just due.

The mercantile marine has in a great measure followed in the wake of the navy; and zinc is now very largely employed in the fleets of all the large companies. Every possible method of fixing it in the boilers has been adopted, with more or less success. Engineers who understood the principle of its action in forming with the iron a galvanic battery, have sought to secure metallic connection by many mechanical devices, while others, convinced of its efficacy, but not understanding its methods, have even thrown it loose into the boilers, to waste and crumble away to no purpose.

Zinc, indeed, had long been used with the object of depositing any minute particles of copper that might find their way into the boiler. It was useless for this purpose, as the Admiralty inquiry fully proved; but wherever it happened to be connected with the iron, it became protective, by setting up electric action, which would continue for a short time, until oxidization of the zinc had broken the electric contact.

A superintendent engineer who was using zinc in his boilers, fixed to the iron, told me he did not believe in the galvanic theory, while in practice he was profiting by it; and when I pointed out this fact, and asked him to explain on what other principle the zinc could be protective, he was unable to answer me.

Another engineer to an important company told me he had a theory of his own, that what was called corrosion and pitting was nothing of the kind, but was solely the result of friction from the circulation of water in the boiler. On the other hand, the majority of superintendent engineers who have some knowledge of electricity and chemistry, are quick to appreciate the truth of the now ascertained cause, and the scientific remedy.

Among the numerous methods adopted for fixing the plates in boilers, the plan patented by Mr. Phillips (formerly a member of the Admiralty Committee), was considered one of the best. It consists in attaching a plate of zinc to a stud or peg, 3 or 4 inches long, projecting from the shell of the boiler, the plate being screwed on tightly by a nut, to ensure close contact with the iron. This system, however, is liable to failure, like all other modes of mere mechanical attachment, as I shall be able to show; and the only means whereby it can be made at all successful is by introducing an excessive number of plates, at great expense, and by constantly examining, cleaning, and renewing them. I have known as many as thirty-eight plates fixed in each of six boilers in one ship on this system, and as many as fifty-six in one boiler of a ship of war on the Admiralty system.

Now, it often happens that when one mind is moved to investigate in a particular direction, another, at a distance, is working to the same end; and men unknown to each other are working out the same problem, and arriving at similar conclusions. So it was in the application of zinc to steam boilers. While Mr. Weston was working up, step by step, to his present system, Mr. Hannay, of Glasgow, an electrician and chemist, alone in his laboratory, or watching experiments in steam factory or sea-going ships, was building up fact upon fact, and coming about the same time to the same conclusion in principle. In the application of that principle he made an important advance on other methods.

I will endeavor, as briefly as possible, to narrate his proceedings, and describe his invention. The investigation was commenced for the Allan Line of steamers, from Glasgow, at the request of Messrs. Allan Brothers, who, like all owners of steam power, were deeply interested in the boiler question.

The common theory held at that time was that free oxygen and carbonic acid in the water were the active causes of corrosion, and Mr. Hannay's first experiments were directed to absorb the oxygen by the ordinary methods known to chemists, with the result, however, that corrosion continued. When an alkali was added to absorb the carbonic acid, priming was caused to such an extent as to be danger-

ous to the safety of the machinery. He may be said to have exhausted chemistry in his endeavor to find a means of stopping the decay; but, although he succeeded in removing every trace of free oxygen and carbonic acid, the corrosion still continued after six months of patient trial. He concluded, therefore, that, while free oxygen and carbonic acid might help to corrode the boilers, they were certainly not the chief causes.

It next occurred to him that certain parts of the boiler more highly heated might, for reasons familiar to science, have their surfaces so altered as to cause them to become electro-negative to the colder parts. This view was particularly impressed upon him from the fact that corrosion so often took place along certain well defined lines, as, for instance, along the sides of the fire tube. Sometimes the corrosion was so deep that there was reason to apprehend collapse of the furnace. The cold blast going to feed the fire kept the part where the corrosion was quite cool, while the flames kept the top very hot.

Starting, then, from these facts, he deduced the theory that thermo-electric currents were set up between the colder and hotter parts of the boiler, and that the colder part, forming the positive pole, corroded by the natural law of galvanic action.

To test this theory, experiments were made with a boiler specially constructed to allow it to be heated in sections, and to stand a pressure of 200 lbs. to the square inch. Two iron plates were fixed in the boiler, one near the top, and the other near the bottom, and both were connected with a galvanometer, so that a current of electricity passing from one plate to the other could be detected and measured. The boiler was heated alternately more strongly at the top or the bottom, with the constant result that whenever the temperature rose above the boiling point, as in a steam-boiler, the cooler plate became positive, and wasted away. Thus the theory was lifted into the region of ascertained fact.

Attempts were made to keep the boilers in actual use more uniformly heated, but if corrosion were stopped in some places, it was sure to break out in others.

It appeared, therefore, that the only way to prevent this corrosion was by making the iron all negative by a current stronger than that set up in the iron itself by differences in temperature. The current was estimated and found to be very small; a weak battery was fitted up, and the positive electrode, or wire, passed into the water of the boiler, the negative electrode being soldered to the outside of the boiler.

After six months' trial with this arrangement, it was found that corrosion had entirely ceased.

Two important facts, therefore, were now made clear; natural electric currents, so to speak, caused corosion, and a stronger artificial current could be made to cure it.

The experimental boiler was then again tried with the same arrangement as before, but it was first filled with dilute acid. The current was kept going for three months, when it was found that the interior of the boiler was still quite free from corrosion, the acid having been powerless to injure it.

The actual natural current between the metals being so very small, it was thought that, instead of a battery a simple galvanic couple, formed by a mass of zinc within the boiler, properly connected with the iron, might be sufficient to overcome it.

Now, the theory of zinc in contact with iron preventing corrosion may be illustrated thus:

Take two pieces of metal, one of zinc and one of iron, and immerse them in a solution of water diluted with acid, both will suffer from corrosion; but connect them with a wire, and you make them at once into a galvanic couple. A current of electricity is set up between them—the corrosion is directed entirely upon the zinc, which crumbles away, while the iron is no longer injured. The zinc is the positive, and the iron the negative pole. Now you have only to continue the plate of iron till it extends all round the zinc and encloses it, and you have a perfect illustration of the manner in which an iron boiler, enclosing a block or mass of zinc, is made as a whole into the negative pole of a galvanic couple, and is thenceforward absolutely protected from corrosion. It will also become evident that if the connecting wire be broken, or the contact between the zinc and the iron

made imperfect by the intervention of any foreign matter, the galvanic current will cease, and the iron of the boiler will corrode as well as the zinc—just as the two pieces of metal were seen to corrode before they were joined by a wire.

The theory, then, of the protection of iron by contact with a more electro-positive metal being unassailable, and experiment corroborating it, inquiry was next instituted to discover the cause of failure in zinc as ordinarily employed.

It was found that, as zinc had been previously used, no proper arrangements were made for ensuring a true and lasting metallic contact. To show how this fact was demonstrated, and at what pains it was ascertained, a narration of one of the numerous experiments made will be interesting: A boiler was fitted with rolled zinc plates attached to studs, on Mr. Phillip's principle, as previously described. Every precaution was used to give perfect metallic contact. The stud was filed bright and made slightly conical, the hole in the zinc plate made to fit tightly, and the nut on the stud screwed home so as to drive the plate into thorough contact with the clean iron. An insulated wire was fixed to the plate, and led, through a stuffing box packed with india-rubber. Another wire was soldered to the outside of the stud. When a small battery and a galvanometer were put in circuit, the current passed from the zinc to the stud, and so round again to the battery, proving that the contact was perfect. There were six plates put in on trial altogether, and the result was that, after three days' boiling, two of the plates had become metallically disconnected from the boiler—that is to say, no current could pass through the circuit. After five days, another plate became useless, owing to the same cause. At the end of twelve days, only one plate was in electrical contact with the boiler. The boiler was opened after thirteen days' steaming, and it was found that none of the plates were really used up, but that a layer of oxide of zinc had formed between the plate and the stud, and the zinc was thus rendered useless. It must be remembered that these six plates were all specially fitted, and ought to have acted thoroughly well if anything could. The sixth plate was sent away with the ship again, but only remained active two days. It was eaten through when the boiler was again opened.

By this and other experiments it was proved that no mere mechanical attachment of the zinc will suffice to insure continued maintenance of the galvanic current, because, no matter how closely the zinc is fitted to the stud, or bolted to the iron, the water creeps in between and soon destroys the metallic contact.

It was also found that the use of plates was faulty. If they are cast, they split up and fall to pieces in a few days, and if rolled, they are only about a quarter of an inch in thickness, and they soon dissolve away.

To meet the various defects in the use of zinc plates, Mr. Hannay designed a ball of zinc, with a copper conductor cast through the center of it, the copper being so combined and amalgamated with the zinc at the junction of the two metals as to form brass, and thus no corrosion could form between them to stop the galvanic current. The zinc is well hammered at a certain temperature, insuring long existence in an efficient condition.

This ball of zinc is called an "electrogen"; it is fitted in any convenient part of the boiler by a simple device, and a wire from each end of the copper conductor is soldered firmly to the iron. From this moment the electrogen keeps up an uninterrupted galvanic current, and the whole of the interior of the boiler is absolutely protected from corrosion so long as any of the zinc remains.

It was ascertained, by further experiments, that a very small surface of zinc was sufficient to afford protection for a radius of twenty-five feet from the point of contact, and the spherical form of the zinc was adopted because it would maintain perfect protection with a minimum of waste, the large surface exposed by plates, in proportion to their bulk, being quite unnecessary. Herein, therefore, was the means of avoiding that waste which the Admiralty Committee stated was "much greater than that due to the protection of the boiler," and for which they sought a remedy.

Two electrogens are found in practice sufficient to protect an ordinary "single-ended" marine boiler, in which, by some engineers, forty or fifty plates would have been considered necessary. The electro-

gens will last for about six months, while the plates would probably corrode away in as many weeks.

The advantages that Mr. Hannay claims for his system, as compared with any employment of zinc plates, are that it is less expensive and more effectual, and that the protection it affords does not depend upon a chance contact that may be destroyed at any moment. But a further gain, perhaps even greater than these, is that it does not allow scale to form in a boiler at any time to a much greater thickness than that of an egg shell, or a coat of paint.

The zinc ball, with its perfect contact, generates a current of greater intensity than zinc plates mechanically fitted, and the consequence is that a portion of the water is slowly decomposed, and the hydrogen that is evolved at the negative pole, all over the surface of the iron and underneath the scale, forces off the scale in thin flakes by mechanical action, as soon as it becomes thick enough to be impervious to the hydrogen. In this way the scale is kept forming and reforming, hanging in loose flakes, or falling off as it becomes detached from the iron.

Thus, all the evils attending incrustation, which have been before enumerated, are avoided. Fuel is saved, burning of the iron is prevented, and chipping becomes no longer necessary.

The reason why scale becomes more hard and coherent under the zinc-plate method as used in the navy, is that while the galvanic current sets up acts in retarding corrosion, it has not sufficient intensity to decompose the water and deposit a layer of hydrogen on the iron; so the scale grows on a firm surface, and is not pushed off by gas evolved beneath it.

When zinc is merely pressed against iron, the two metals really touch each other at minute points only, and thus great resistance is introduced. Resistance in this case means that the current is destroyed to a certain extent as electricity, and converted into heat; just as the resistance of the break destroys the motion of a train and converts it into heat. Then the water creeping in between the two metals, and forming a non-conducting oxide between the two surfaces, increases the resistance, and ultimately prevents the passage of the current altogether.

When resistance is prevented, and the full intensity of the current is allowed to pass from the zinc to the iron, and back through the water, hydrogen is slowly accumulated at the iron surface, yielding protection from corrosion, and, at the same time, loosening and throwing off the scale.

The value of any discovery that will prevent the formation of hard scale in land boilers can scarcely be over-rated. These boilers in which fresh water is used do not suffer so much from internal corrosion; but the calcareous scale which forms in them has been always a great source of trouble. Compositions have failed, and zinc plates are ineffectual to remove it.

The electrogen, however, seems to have solved the problem; and, to make it sufficiently active in fresh water, the homeopathic principle is applied of *similia similibus curantur*. A small quantity of salt, which is the active corrosive agent in sea water, is made, not only to cure the disease of corrosion which it actuates, but to stimulate an electric current which entirely disposes of incrustation.

Sea water contains on an average 32 to 38 parts of salt in 1,000. Mr. Hannay's homeopathic dose is a-half an ounce to a gallon, or 4 parts to 1,000; and, as no proportion less than 8 times this amount has any effect on iron, no harm can be done to the boiler, even if it were not protected by the zinc. Into brewers' "tanks" and other boilers, the water from which is used for manufacturing purposes, salt, of course, cannot be admitted; but this difficulty is overcome by a simple device, by which the salt is kept separate from the body of the water.

Land boilers, in many districts, would become quite unworkable through the accumulation of scale, if it were not chipped off every five, six, or eight weeks—of course at considerable expense—the boiler lying idle during the process. With electrogens it has been proved that boilers will work more than twice the usual time without any necessity for opening them, and that then the loose flakes of scale may be cleared out in a short time with a hose and a broom. Meantime, no thick scale being allowed to form, it becomes perfectly harmless;

the coal consumed does its full work, and steam is made more freely.

Engineers who have witnessed the results in several recent trials, have stated their opinion that the discovery will revolutionize the treatment of land boilers.

In conclusion, a further and valuable addition has been made to the marvelous applications of electricity, which have pre-eminently distinguished the last decade of scientific discovery.

But there is no finality in human invention. More light will dawn, and with it new marvels will arise. It may be that, before another decade has run its course, electricity or atmospheric power will have superseded steam, and the huge iron boiler of to-day will be looked upon as the clumsy expedient of an ignorant generation.

Till then, while the evils we have been considering exist, and are potent for the destruction of life and property, inquiry into their nature and origin is both desirable and necessary, and time will not have been wasted in seeking to discover the most effectual remedies.

REPORTS OF ENGINEERING SOCIETIES.

AMERICAN SOCIETY OF CIVIL ENGINEERS, May 7, 1884.—Vice-President Wm. H. Paine in the chair—John Bogart, Secretary.

Ballots were canvassed, and the following candidates were elected:

As members—Willis D. Chapman, Akron, Ohio; John E. Cheney, Boston, Mass.; Arthur DeW. Foote, New York City; George S. Gatchell, Buffalo, N. Y.; Henry L. Marindin, Boston, Mass.; Evelyn P. Roberts, Fort Hamilton, New York Harbor, N. Y.; Jesse W. Walker, Pittsburgh, Pa.

As juniors—Henry Goldmark, New York City; Samuel C. Weiskopf, Milwaukee, Wis.; Herbert A. Young, Toledo, Ohio.

As honorary member—Gen. John Newton, Chief of Engineers U. S. A., Washington, D. C.

A paper by James Christie, M. Am. Society, C. E., on "The Strength and Elasticity of Structural Steel, and its Efficiency in the form of Beams and Struts," was read by the author. He said that the various grades of steel possess such a range of physical properties, that it is impossible to consider the metal as one might treat of iron.

It is customary to denominate the grades of steel by the percentage of carbon they contain. The higher the carbon, the higher the tenacity of the steel and the lower its ductility. Steel whose carbon is below fifteen hundredths per cent. is conventionally known as mild or soft steel. The steels subjected to the tests described in this paper were of two distinct grades—mild and hard; both being products of the Bessemer convertor, the hard steel having thirty-six hundredths per cent. of carbon, and the mild steel twelve hundredths per cent. The tensile tests were made on strips about 24 inches long to which were clamped plates exactly 12 inches apart. The compression tests were made on specimens 12 inches long inserted in a tube and the space between the specimens and the tube filled with fine sand.

The tests on transverse resistance were made on bars of three or four inches diameter, and on solid flanged beams from three to twelve inches deep, all being supported at the ends and loaded in the middle.

Extended tables were then presented of these various tests, and it was stated that the results showed that the elasticity of steel and iron is practically uniform; the steel may stretch less than the iron in tension, but the steel shortens most under compression.

Transversely if there is any practical difference the advantage of stiffness probably belongs to steel, but the elasticity of both metals is so close and uncertain that further experiments may modify the average results here found. The specimens show that the elastic limits for tensile and compressive stress for the different grades of steel are practically equal per unit of section, and the transverse resistance is approximately proportionate to the longitudinal resistance, and that the strength of the material indicated on tensile stress will serve as a comparative measure of the absolute strength of iron, or of either grade of steel; but as the transverse elasticity is practically alike beams of iron or of either grade of steel of the same length and section will deflect alike under equal loads below the elastic limit of iron.

Tables were presented of experiments on flat-ended struts of both mild and hard steel. It was stated that the experiments on direct tension and compression prove that the elastic limits of steel of any particular grade are practically equal per unit of section for either direction of stress. A similar equality is known to obtain with iron. Therefore, for the short struts in which failure results from the effects of direct compression, the tensile resistance of the material will serve as a comparative measure of strut resistance. As struts increase in length the lateral stiffness becomes a factor of increasing importance. The transverse elasticity of steel and iron does not vary much. The tendency will be for struts of steel and iron to approach equality of resistance as the lengths are increased. Mild steel will fall to equality with iron when the ratio of length to least radius of gyration is about 200 to 1. Hard steel would fall to practical equality at the point beyond the bounds of practice.

This paper, and the paper previously presented by Mr. Christie giving experiments on the strength of wrought-iron struts, were then discussed.

Mr. A. P. Boller expressed the opinion that the variations in the compressive resistance of iron shown by these very careful experiments were so great that it was impracticable from them or from any other experiments, so far as had yet been made, to prepare a formula which

would ever give satisfactory results, and that dependence must be placed upon experimental charts which will express extreme values for all sections progressively determined.

Mr. Onward Bates considered that the experiments developed the great importance of placing the center line of pressure coincident with the center of the struts. If this could be done perfectly, a round-ended strut would be as good as a flat-ended one. In actual practice in the construction of bridges the methods of securing the ends of such struts are so various that it is impracticable to make from such experiments a table of safe loads. The only safe practice is that of low unit strains corresponding to the lowest results of recorded tests.

Prof. E. A. Fuerkes considered that the areas of cross sections should be obtained by direct measurement instead of deriving them from the weight and length of the bars, particularly when the specific gravity of the material is not determined. The reason why an accurately-centered straight bar behaved as a flat-ended strut when hinged, is due to the friction developed by pressure on the bearing of the hinge, and the early failure of flat-ended struts was probably due to the want of parallelism between the planes at the extremities, or the one or both of these planes being warped surfaces. Since a bar, very long in proportion to its radius of gyration, fails with a comparatively light load without permanent injury, it would seem proper that such load should be gived a name other than ultimate load, the latter being restricted to its bearing on the elastic limit.

Mr. Theodore Cooper considered the experiments of Mr. Christie most valuable, particularly in carrying out a complete series with different end connections upon the same class of materials. The paper shows that slight changes in the direction of the lines of applied forces produce great changes in the results. By interchanging different sizes of ball and socket joints it shows the influence of the size upon compressive resistance of the struts. It gives a more complete knowledge of the action of struts of high ratios of length to transverse dimensions than before existed. The method of using the least radius of gyration, instead of the least dimension, gives a fair comparison between the various forms. Attention was called to the relation of the ball and sockets to the transverse dimensions of the struts, and diagrams were presented by Mr. Cooper, showing the influence of the size of pins relative to the width of the struts. From the great effects of non-centering the line of applied force upon columns and of initial, though minute, bends in the materials, and the increased influence of possible side blows, it is very important not only to keep the working strains within proper limits, but also to specify a limit to the number of diameters to be used in all columns. In recent specifications this limit has been about at 45 diameters, corresponding approximately to about 120 radii of gyration for the usual forms of bridge columns. With this proviso a practical formula may be reduced to very simple forms.

Mr. E. B. Dorsey presented some comparative tests of iron and steel.

The subject was further discussed by Messrs. Bouscarew, Chas. E. Emery, Pegram, P. Roberts, Jr., Towns and Christie.

ENGINEERS' CLUB OF PHILADELPHIA.—Regular Meeting, May 3.—Mr. S. N. Stewart, Visitor, exhibited a model of his River or Current Motor. Paddles are placed upon cranks and maintained in a vertical position by long floating vanes or tails. The cranks are placed upon posts, rafts or boats in the stream and journaled at the water-line, thus keeping one-half of the paddle surface in action, while the common floating-wheel or current-wheel only keeps one-tenth of its surface in action. In Mr. Stewart's motor a 10 ft. arm carries a paddle 10 ft. high. For particulars concerning this engine, he refers to "Commercial Relations of the U. S.," 1881, p. 682. or New York *Daily Tribune*, June 21, 1881. Mr. Stewart said "the only way to utilize the power of large rivers is by current-motors, for dams are not permitted and are too expensive; that a current of five miles an hour has one hundred times the pressure of wind at ten miles an hour, and that, as the current soon regains its normal velocity, it can be used over and over"

Mr. Thomas M. Cleemann read a paper on an Economical Form of Bridge Truss. In outline it resembles Whipple's arch truss, inverted so as to bring the curved portion in tension, but differing from it in having the chord made to resist tension and being anchored to the abutments. In this way the only parts of the bridge in compression are the vertical posts, and the extra material, required to stiffen the upper chord in an ordinary bridge, is saved. To illustrate the correctness of his conclusions, Mr. Cleemann had a small model made of pink wrapping twine that broke with five and a half pounds, and with posts made of wooden knitting needles. This model, by calculation, ought to have borne about eleven pounds. After loading it with a pound weight at each of the seven panel points and letting it remain for a little time for the inspection of the members, he added first two more pounds at the centre, and afterwards two pounds more. With this eleven pounds the model hesitated a moment and then broke at each abutment, nicely illustrating the author's conclusions. He likewise gave the saving of material in such a bridge over a Pratt truss of five hundred and sixteen feet span, and pointed out its advantages for military purposes, where facility of transportation is a prime object, and a bridge almost entirely of rope is especially valuable on this account.

Mr. Henry C. Roney exhibited a section of four-inch Wooden Water Pipe and Joint, found about two feet below the surface while excavating a trench for the conduit of the Philadelphia Sectional Electric Underground Co., on Chestnut Street, between Fourth and Fifth, and described those which had been found on Chestnut and Market Streets during the progress of the work. These are interesting as showing the durability of such pipes and connections, under the conditions to which they had been subjected.

Mr. W. G. Neilson read some notes on the

recently published Report of Gun Foundry Board. The recommendations embodied in this report, in regard to the establishment of a gun factory at Watervliet Arsenal, West Troy, New York, for the manufacture of guns for the Army, and at Washington Navy yard for the Navy, and that the Government should depend upon the steel manufacturers of the country for its forged steel and should simply finish the guns in its factories, were referred to, as also were the interesting facts colleted by the Board, during their visit to Europe, in regard to the character of steel used for guns.

The secretary exhibited, for Mr. J. H. Harden, a neat Topographical Model of the Jones Iron Ore Mine in Berks Co., Pa., and briefly explained the method by which such models are constructed.

ENGINEERING NOTES.

THE INSPECTION AND TESTING OF IRON ROAD-BRIDGES IN GERMANY.—According to a decree recently published by the Minister for Public Works, all iron bridges on public roads are annually to be subjected to rigorous inspection and tests.

The parts to which special attention is to be directed in the inspection are:

1. The girder-beds and the brickwork of the piers and abutments.

2. The bed-plates with regard to normal position, freeing them from rust, &c., and eventually seeing that they are in perfect working order.

3. The riveting at the junctions of bracings, &c., with the booms, especially the existence of loose rivets at points where the greatest strain is borne.

4. The separate parts of the bridge; whether any fractures have occurred at the rivet holes, and whether bending, rust, or want of paint are manifest.

After the inspection of the bridge it will be evident whether any measurements are required to be taken; if so they are to be made with a view of ascertaining—

(*a*) The normal height of the bearing-plates.

(*b*) The height of the center of the bridge, and its camber when unloaded.

(*c*) The amount of oscillation produced by vehicles passing over the bridge.

If, after the above inspection and measurements have been made, the state of the bridge should be doubtful, load-tests are to be resorted to, in order to bring out more prominently any defects which may exist in the structure.

For measuring the deflection a level is generally to be employed, but the use of other means and apparatus in suitable cases is allowed.—*Proceedings Inst. C. E.*

ON RIVER EMBANKMENTS.—The embankments of the Po between Cremona and Casalmagiore were originally placed from 2½ to 3 miles apart, leaving long strips of valuable land between them and the ordinary channel of the river. In many places large tracts of this intervening land have been enclosed by banks, which might be thought to act as outworks to the embankments, and to afford them additional protection. Instead of this, however, they have frequently proved to be sources of danger, as they are more liable to be damaged by floods, and if the river bursts through them the rupture of the embankments frequently follows, the reason being that as these latter always stand dry, except when the banks have failed, they do not get the benefit of the action of the water in filling up small cavities, nor is there any opportunity of discovering defects till a flood comes and it is too late. It is believed that in many instances in which disastrous breaches have been made in the embankments these have been due entirely to the effect of the banks. This danger was illustrated and happily averted in one instance. The embankment of the Po between the Olona and the Lambro protects an area of 14,000 acres, with a population of nine thousand seven hundred. Between this and the river several tracts of land have been surrounded by banks. In October, 1882, one of these banks, enclosing 355 acres, was threatened by a flood, when the engineer in charge ordered two cuts, of about 70 feet each, to be made in it, so as to allow the water to flow through gradually and to reach the embankment slowly. It was then found that defects existed in this embankment, which began to be undermined by water; but as there was then time to remedy them, the country was thus saved from an inundation, which would certainly have taken place had the river forced its way uncontrolled through the bank, as it would then have poured with such force against the principal embankment that it would have been impossible to repair it.

Mr. Pestalozza considers that these banks should either be removed altogether, or else made entirely separate from the embankments, or in some cases, when villages have been built under their protection, should be raised and strengthened so as to act as the principal embankments of the river.

Mr. Rossi, on the other hand, while admitting that these banks are often improperly constructed and become a source of danger, thinks that in most cases they afford real protection, and are, in fact, embankments. He recommends that they should be kept at a lower level than the embankments, the exact height varying in different localities, but being somewhat below the level of ordinary floods, which would then flow over them and give the embankments the benefit of the wash of water which is required to keep them in good order; the damage which the enclosed lands would sustain by occasional flooding would be compensated by the deposit of rich mud left by the water.—*Abstract of Inst. of Civil Engineers.*

IRON AND STEEL NOTES.

ON THE BURNING OF IRON AND STEEL.—Iron that has been raised too near its temperature of fusion and slowly cooled, is designated as "burned" or overheated metal. It is both red-short and cold-short, and exhibits a coarse, crystalline structure, and a bright, glistening fracture. Such iron contains oxygen. But this oxygen is not, as is commonly believed, de-

rived from without during the heating, but it was previously contained in the iron itself through the medium of the scoria or slag-impurities mixed with it. When the iron is raised to the fusing heat, or near it, a chemical reaction takes place; the metallic iron reduces the sesquioxide to protoxide, which, by being dissolved in the iron, alters the properties of the latter. The coarsely crystalline quality of iron so treated is not due to the presence of the oxygen. The metal usually contains a notable quantity of phosphorus, which is well known to give a coarse grain accompanied by the quality described as cold-short. The crystallization takes place during the slow cooling while at rest. The greater the proportion of phosphorus present the lower is the temperature to which the iron may be raised without being burned. Pure iron should not take up more than 0.25 per cent. of oxygen in solution. Though this substance does not greatly affect the ductility of the metal when cold, it acts like sulphur on its malleability.

The qualities of steel also undergo change when heated to a high temperature, or when subjected to a lower temperature for too long a time. The richer the steel is in carbon, the lower is the temperature at which the change take place. Therefore, the harder the steel the more carefully is it to be dealt with in the fire. Such overheated steel becomes coarse grained and brittle; that is, cold-short. If the temperature be increased, showers of sparks are thrown off, and the steel is said to be "burned." The alteration brought about in this way has generally been attributed to a diminution in the proportion of the carbon constituent, though this assumption is not warranted by the results of analysis. The presence of manganese and silicon is of more weighty consequence. When steel containing these is heated it is not the carbon, but the manganese and silicon that first become oxydized, and there results an important change in the properties of the steel. Later the carbon is oxydized; and while the oxide of carbon escapes those of the manganese and silicon remain behind, and the whole molecular structure of the metal is altered. If the heating be carried still farther the iron will next be oxydized. A cast-iron furnace door, exposed for several years to the flame of a coal fire, was found to contain 27.8 per cent. of oxygen, in combination with iron, sulphur, nickel, copper, phosphorus and arsenic. The cause of the sparks is not the combustion of the carbon, and the consequent generation of carbonic oxide gas, but the escape of gases imprisoned in the steel. Similar results may be brought about by exposing the steel to a lower temperature for a longer time; the oxidation of the constituents will, in this case, be effected in the order mentioned above, the only difference being in the slower action. Steel altered in this way is well described as "dead." A regeneration of the metal by mechanical treatment is hardly possible, since the original chemical composition cannot be restored by such means.

RAILWAY NOTES.

The Progress of Canadian Railways.—The official statistics show that 1,275 miles of railway were built in Canada last year, making a total of 8,805 miles under traffic, and when the lines at present under construction are completed, which will be within two years, the railway system of Canada will comprise over 11,400 miles. The paid-up capital was increased to $494,271,264, or 19 per cent. The gross amount of freight carried during the year was 13,266,255 tons, the gross receipts for which were $21,320,208. The gross receipts, together with those for mails and sundries, were $11,924,377, making the gross revenue $33,244,585—an increase in receipts over those of the preceding year of $4,216,796. The net earnings for the year were $8,552,928—an increase of nearly $2,000,000.

Steam Tramways in Burmah.—Reports have reached here of the starting of the steam tramways of Rangoon, owned by Messrs. Darwood & McGregor, of that city. The engines are by Messrs. Merryweather & Sons, and are of the Stockton type, which have successfully run them for upwards of two years. Mr. Henry Bateman, from the works of the builders of these engines, is locomotive superintendent. There are excellent workshops and first-class tools for carrying out the necessary repairs. The report just to hand states that the engines are running continuously, each drawing three large cars crowded with passengers, and commercially it is expected that this will be one of the greatest successes in Rangoon. Some more engines will be built by Messrs. Merryweather for the extensions, also some special double bogie cars of teak with iron frames. We shall shortly illustrate the cars and workshops of this tramway.

Indian Railway Statistics.—The second part of the administration report on the railways of India for 1882-83, recently published in Simla, contains elaborate statistics regarding the lines serving India, and furnishes information which is of great interest now that the railway policy of the Indian government is under discussion. There are four classes of railways in India, viz., nine state railways under the control of the government, thirteen provincial state railways, six native state railways (the most important of which is in the Nizam's territory), four lines belonging to assisted companies, besides six lines controlled by the government of Bombay and two by that of Madras. As regards the Indian government railways, the East Indian and some others pay well, while a few are worked at a dead loss, but, taken all round, they now yield a surplus in aid of the Indian exchequer. Speaking of Indian railways generally—that is, of the whole 10,000 miles of system—they earn about £1,525 gross per mile, about one-third of the earnings of English railways. The working expenses, too, are less than what we might expect, considering the breaks of traffic, and the fact that most of the coal used has to be imported from England. They amount but to 49.94 per cent. of the receipts, against 52.34 per cent. for England and Wales, 49.51 per cent. for Scotland, and 54.88 per cent. for Ireland. The net receipts are sufficient to yield 5.37 per cent. on the capital expended, that is, a shade over the

5 per cent. guarantee. The East Indian yields over 8 per cent., the guaranteed lines 4.94 per cent., and the state lines a little over three per cent. The gauge controversy is opening up a burning topic. There are no less than five railway gauges in India—the 5-foot 6-inch, or broad gauge, the 3-feet 3-inch, or meter gauge, the 4 foot used on the Azimganj Railway, the 2-foot 6-inch gauge of the Gaekwar of Baroda's line, and the 2-foot or military gauge of the Himalayan Railway. Practically the contest now lies between the broad and meter gauges, and as the most important lines have been laid on the former principle, opinion inclines to the view that the broad gauge is the proper one to universally survive. At any rate, what is now desired is uniformity, as the present breaks of gauge and consequent shifting of goods add considerably to the cost of transport.

ORDNANCE AND NAVAL.

THE COLLAPSE OF SHIPBUILDING.—After attaining last year to the highest point that it has reached in the history of the industry, shipbuilding at the North-Eastern ports has in the first three months of 1884 collapsed. It has been definitely stated that there are now about 7,000 shipbuilders unemployed on the rivers Wear and Tyne. If this statement be even exaggerated, it must be confessed that there is an enormous falling off in the number and the tonnage of vessels in course of construction. On the Tyne and the Wear the number of the vessels on the stocks is only about one-half of those on the stocks at the same date last year; and at the other shipbuilding ports there is also a falling off, though not quite so marked. Again, out of the vessels on the stocks there are some, the progress of which is stopped; and as others are launched their places are not taken up. It is thus clear that there will be an enormous falling off in the tonnage of the vessels built at the North-Eastern ports during the current year, and it is probable that the completeness of the collapse will be one of the reasons that lead to the conclusion that the recovery, if not very rapid, will be not so long deferred. The loss of vessels still goes on, and as the work of the steamers had been restricted by the enormous stocks that had accumulated, and as these stocks are now falling off, it may be fairly concluded that the demand for tonnage will recover with more speed than had been thought likely. So complete a collapse as has been witnessed, and is being witnessed, may lead to a revival in the trade at no very distant date.

THE MANN GUN.—Mr. H. F. Mann, of Pittsburgh, has been advised by Sir Joseph Whitworth & Co. that the steel tube for his breech-loading rifle has been shipped, and that the steel jacket and other parts that are being made by that company will be forwarded shortly. The tube and other parts are made of the Whitworth fluid-compressed steel of the best quality. The tube is 17 feet long, 6½ inch bore, and weighs about 4,500 lbs. All the parts furnished by the Whitworth Company will weigh some 14,000 lbs., and will be finished complete, ready to be put together by the South Boston Ironworks, of Boston, Mass., which has been the contract with Mr. Mann for completing the gun. The total weight of the weapon will be about 20,000 lbs. Mr. Mann has also a contract with the Ordnance Department for 250 projectiles to weigh 110 lbs. each, to be used in the test of his gun. These projectiles are now being made in Pittsburgh, and will be forwarded to the Government proving grounds at Sandy Hook, New York Harbor, as soon as completed. The charge of powder to be used in testing this gun will be from 30 to 40 lbs.

THE ARMORPLATE TRIALS IN DENMARK.—The *Army and Navy Gazette* gives full particulars of the experiments carried out on the Island of Amager on March 20 and 21. The four plates were bent on an inside radius of 10 feet 9 inches, each formed a separate target, the English plates being fixed by means of twelve bolts to the backing, that of Marrel Freres by eleven, the Schneider solid steel plate by sixteen bolts. A 15-centimeter Krupp gun, 35 calibres long, and an 18-ton Armstrong muzzle-loading gun were used. The projectiles consisted of 5⅞-inch and 10-inch steel shell of the latest pattern manufactured at Essen, also 5⅞-inch chilled-iron shell and solid 10-inch chilled shot of Swedish manufacture. The latter was only used against the Cammell compound plate. The range was 100 meters. On March 20 the experiments commenced with a round of steel shell at each plate. All the four shells struck the plates full in the center, penetrating the Marrel plate considerably, two large cracks starting from point of impact to the edges of the upper and right side of the plate. The Cammel plate was slightly penetrated, and showed a few surface hair cracks. The Brown plate showed deep cracks running from the point of impact to the left side of the plate. The shell penetrated the Schneider plate to a considerable depth, and cracked it in half from top to bottom through the point of impact. The next experiment was made on the left-hand lower corner of each plate, the 10-inch gun being fired with steel shell. The first shot knocked the whole left side of the Schneider plate off its target. The lower part of the Marrel plate was completely wrecked; the shell, passing through the target, was picked uninjured a long distance in the rear. The English plates broke up the shell as they passed through. The Cammell plate showed a few additional surface cracks; the shell, striking the Browne plate somewhat low down, broke off the corner. On the 21st experiments were resumed; a solid 10-inch chilled-iron shot was fired, with a charge of 63 lbs. of powder, at the Cammell plate. Although the shot did not penetrate the compound plate, the target was flung bodily to the rear. A 5⅞-inch chilled-iron shell was next fired at the Brown plate. This opened up a horizontal crack in the plate through its entire thickness, breaking it into three pieces, a similar shell completely destroying all that remained of the Marrel plate. In these trials 467 lbs. weight of metal were fired at the Schneider plate, 569 lbs at the Brown and Marrel plates, and 832 lbs. weight at the Cammell plate.

BOOK NOTICES.

SHAVINGS AND SAWDUST. By "OBSERVER." Buffalo: C. A. Wenborne.

The care, operation and designing of wood-working machinery form the material for the work bearing the above quaint title.

The author evidently knows what is most desirable to be learned by the inexperienced in this branch of industry, and he certainly has a direct way of imparting the facts and principles which he desires to communicate.

THE ELEMENTS OF THE HELIOGRAPH. By FRED'K. K. WARD. Washington: Signal Office.

The increasing use of heliotrope signaling in extended surveys will serve to create a demand for this little essay among surveyors.

It requires but little mechanical skill to construct a serviceable instrument, and the suggestions of this writer explain sufficiently the necessary dimensions for all practicable limits of surveying.

THE SPECIAL CHARACTERISTICS OF TORNADOES. By JOHN P. FINLAY. Washington: Signal Office.

This is issued in the form of a report of a Signal Service officer to Gen'l Hazen.

The phenomena that precede or follow the tornado, the changes of pressure, temperature and direction of air currents, the electrical manifestations, are all carefully grouped and described.

All students of meteorology will read with interest this essay, prepared, as it is, by an expert, who has been fitted by professional training for the work of collating such data as shall best aid in the solution of one of the chief meteorological mysteries.

THE STUDENT'S HAND-BOOK OF PHYSICAL GEOLOGY. By A. J. JUKES-BROWNE, F. G. S. London: George Bell & Sons.

The author of this compact little treatise explains apologetically that another book on physical geology might seem uncalled for while such works as those of Geike and Green are accessible to students. But he adds, "there does appear to be room for a book of more modest pretensions, arranged on a different plan, and issued at a more moderate price."

The work is divided into three parts: Dynamical Geology, Structural Geology, and Physiographical Geology. The second part seems to be of more immediate value to American students, as it gives a concise classification of igneous rocks.

An excellent book for students.

LEGAL CHEMISTRY. By A. NAQUET. Translated by J. P. Battershall, F. C. S. Second edition. New York: D. Van Nostrand.

This new edition exhibits an addition to the well-known first book in a chapter on Tea and its adulteration. The interest lately exhibited in this particular form of sophistication seemed to the editor to call for a simple and concise method of examination which would include the requisite tests without entering upon an exhaustive treatment of the subject.

The experience of Dr. Battershall in this line of testing in the United States Laboratory renders this supplement valuable.

The Bibliographical Appendix has been considerably extended.

MISCELLANEOUS.

THE following method of coloring soft solder, so that when used for soldering brass, the colors may be about the same, is given by the *Metallarbeiter:* First prepare a saturated solution of sulphate of copper—bluestone—in water, and apply some of this on the end of a stick to the solder. On touching it with a steel or iron wire it becomes coppered, and by repeating the experiment the deposit of copper may be made thicker and darker. To give the solder a yellow color, mix one part of a saturated solution of sulphate of zinc with two of sulphate of copper, apply this to the coppered spot, and rub it with a zinc rod. The color can be still further improved by applying gilt powder and polishing. On gold jewelry or colored gold, the solder is first coppered as above, then a thin coat of gum or isinglass solution is applied and bronze powder dusted over it, which can be polished after the gum is dry and made very smooth and brilliant; or the article may be electro-plated with gold, and then it will all have the same color. Quoting from a German source, the *Scientific American* says: On silverware the coppered spots of solder are rubbed with silvering powder, or polished with the brush and then carefully scratched with the scratch brush, then finally polished.

IN illustration of the tendency of dust to move from hot and to deposit itself on cold surfaces, the following experiments were recently described before the Royal Society of Edinburgh by Mr. J. Aitken:—Two mirrors, one hot and the other cold, fixed face to face and close to each other, were placed in a vessel filled with a dense cloud of magnesia, made by burning magnesium wire. After a short time the mirrors were taken out and examined. The hot one was quite clean, while the cold one was white with magnesia dust. In another experiment a cold metal rod was dipped into some hot magnesia powder; when taken out it had a club-shaped mass of magnesia adhering to its end, while a hot rod attracted none. This tendency of dust to leave hot surfaces and attach itself to cold ones explains a number of familiar things; among others it tells us why the walls and furniture of a stove-heated room are always dirtier than those of a fire-warmed one. In the one case the air is warmer than the surfaces, and in the other the surfaces are warmer than the air. This effect of temperature is even necessary to explain why so much soot collects in a chimney. It explains something of the peculiar liquid-like movements of hot powders, and perhaps something of the spheroidal condition. For practical application, it is suggested that this effect of temperature might be made available in many chemical works for the condensation of fumes, and that it might also be used for trapping soot in chimneys.